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EVOLUTION OF THE ARCRONOGRAPH.

A NEW INSTRUMENT WHICH INSPECTS WELDS, CLASSIFIES WELDERS, AND GRADES WELDING ELECTRODES.

By BELA RONAY.*

Electric arc welding is rapidly assuming a position of paramount importance in naval construction, due to the demand for lighter weights and increased strength of joints. Naval authorities are not in the habit of accepting new methods of construction until they have been proven satisfactory by the test of service to the point where they can meet fully the rigid requirements of the Navy. Owing to the fact that the Bureau of Engineering of the Navy Department is primarily concerned with high efficiency and absolutely trustworthy welds, as applied to pressure vessels, their interest was turned towards the fundamentals of welding, for even

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casual study made it evident that the quality of the electrode used was of utmost importance in affecting the quality of the resultant weld; considering, of course, the quality of the weld metal itself, as well as its fusion to the base metal, and finally the thermal effect of the weld metal on the base metal. Hence, an investigation was authorized in July, 1931, at the U. S. Naval Engineering Experiment Station, Annapolis, Maryland, which was to result in data from which specifications could be written that would insure the kind of welds necessary for Naval use. A new Welding Laboratory was established there.

The leading welding electrode manufacturers of the country enthusiastically cooperated by furnishing, free of charge, generous samples of their best welding wire to the station.

The investigation started, not with the idea of determining which of the various electrodes submitted was the best, but rather what factors in an electrode made it superior to some other electrode. In other words, the object of the investigation became the determination of the governing factors of electrode performance.

Since, in electric arc welding, the means of deposition is the arc itself, it was considered logical to study the behavior of the electrodes while under the influence of the arc; *i.e.*, at the point of fusion, transfer and resolidification. The investigators found their first cue in oscillograms obtained during the deposition of several types of electrodes. A study of such oscillograms, together with a study of ultra-high speed photographs of the arc, obtained by them and others, tended to strengthen the belief that the manner of transit of the metal through the arc must be a prime factor in the performance of any electrode. (Figure 1 shows three typical bare electrode oscillograms.)

The next step in investigating this angle of electrode performance led to a "decelerated drop testing." This method employed a graphite plate instead of base metal. Since the graphite plate did not melt at the temperatures developed by the electric arc, it was permissible to cut down the power input that would normally be necessary to melt the base metal preparatory to reception of the melted electrode metal. Thus an electrode could be deposited with a current density of ½ to ⅝ of its normal requirement. Thus the

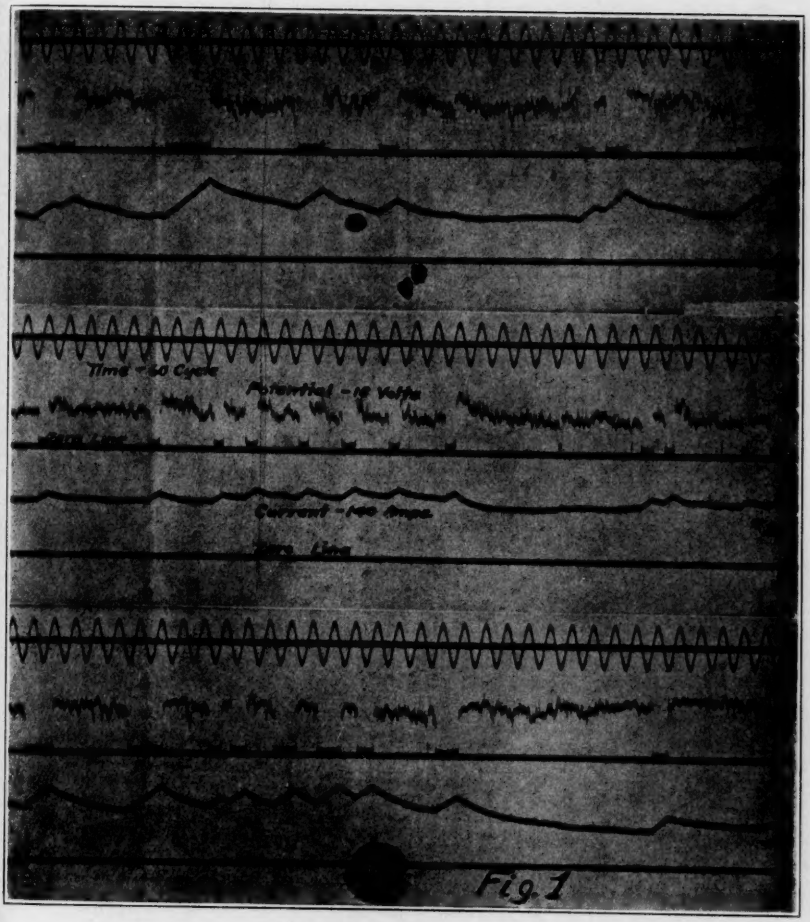


Fig. 1

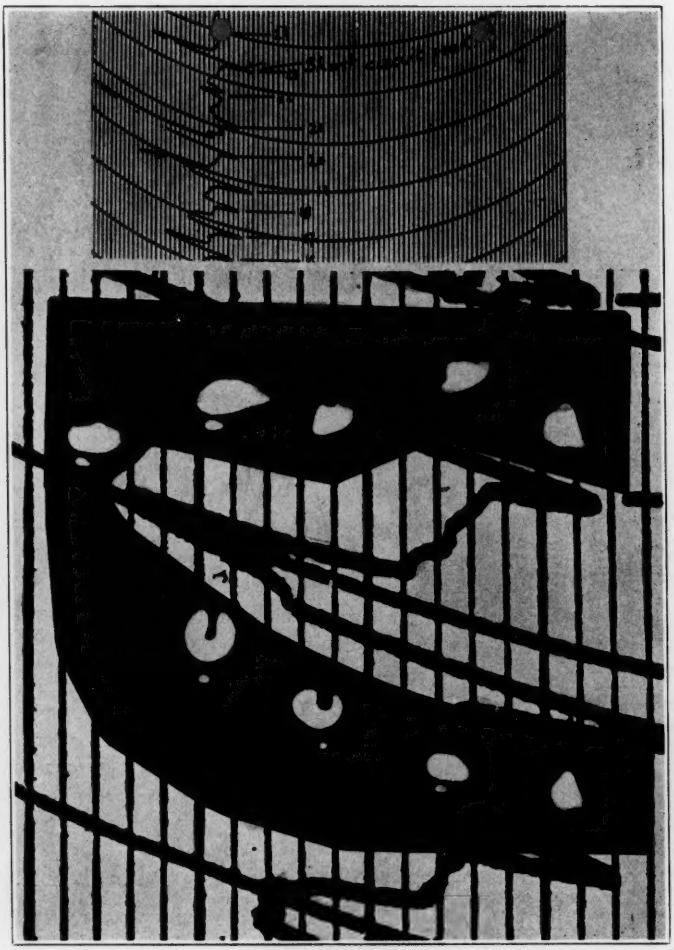


FIGURE 4.

deposition was slowed down and the investigator could, at ease, observe the metal at the tip of the electrode. What was seen is this:

BARE OR WASH-COATED ELECTRODES.

Upon establishment of the flaming arc, the tip of the electrode begins to liquefy, a drop forms; then when the drop reaches a certain volume, it begins to whirl around, necking away from the tip of the electrode and simultaneously assuming the shape of a pear. When the neck has grown long enough to permit the base of the pear to touch the graphite plate, the arc extinguishes momentarily and then the drop (the stem of the pear) breaks away from the electrode. Immediately the arc is reestablished and a new drop commences to form.

HEAVILY COVERED ELECTRODES.

The essential difference between the behavior of heavily covered electrodes and of bare or coated electrodes is that with the former one can not readily observe the formation of the drop, as it takes place within the covering, which, while consuming itself during the formation period, does so at a considerably slower rate than does the electrode itself. The presence of the drop or globule does not become evident until the completion of its formation, when it is shot through the arc at a high velocity, without extinguishing the arc entirely; however, a decided flickering or lowering of the intensity of the arc occurs at this point.

Repeated deposition of electrodes, previously selected and tested for uniformity of composition and heat-treatment by magnetic analysis yielded the following information:

Under identical current conditions, the lower the carbon content of an electrode (regardless of its surface finish) the larger is the volume of the individual drop.

Analyzing the corresponding graphic charts of each deposit as recorded by a strip chart ammeter, it became also evident that in the case of bare and coated electrodes, the longer the formation period, the larger is the volume of the individual drop and the longer is the whirling, low-potential period.

Covering the electrode with a more or less heavy refractory sleeve or coat does not change its basic behavior; the volume of the individual drop remains proportional to the carbon content of the metal core, but the whirling period may be comparatively reduced or almost eliminated, depending upon the efficacy of the covering. (In the above statements, referring to the carbon content, it is assumed that the manganese and other ingredients are present in the normal proportion for good grade welding electrodes.)

The procedure of drop test depositing above described, although a relatively simple process, requires a great deal of skill and close attention to details to create and maintain exactly similar arc and current conditions from drop to drop and from electrode to electrode. In order to arrive at sound conclusions concerning a given type and size electrode the procedure of drop testing has to be carried through repeatedly, discarding all experiments and departures from standard, until the operator is thoroughly familiar with handling the type of electrode under test.

At the start of the investigation there was no automatic apparatus suitable for this kind of work (recording test results graphically and chronologically) and much time and effort was wasted in eliminating erratic results which crept in from time to time, due to unavoidable human irregularities.

However, such instruments have now been developed and assisted greatly in the final solution of the problem. They will be explained and described at the end of this article.

The summation of these tests is shown by Figures 2 and 3. They refer to 3/16-inch diameter electrodes. The charts show that the basic influence of the heavy covering through all carbon ranges is the increasing volume of the individual drop. These charts, however, do not show the time ratio between the formation periods and the whirling (transfer) periods which correspond to the individual drops. These periods are discernible during the drop deposition and are capable of evaluation by studying the ammeter records. It was of great importance to know whether or not the same time relationship is maintained between formation (high potential) periods and whirling deposition (reduced potential) periods during actual welding as were found to exist during drop deposition.

The oscillograms that automatically suggested the trend of the investigation seemed to confirm the belief that the drop deposition is portraying the time behavior during actual welding, except that the actual frequency of the whole cycle of drop deposition changes in proportion to the increased power input.

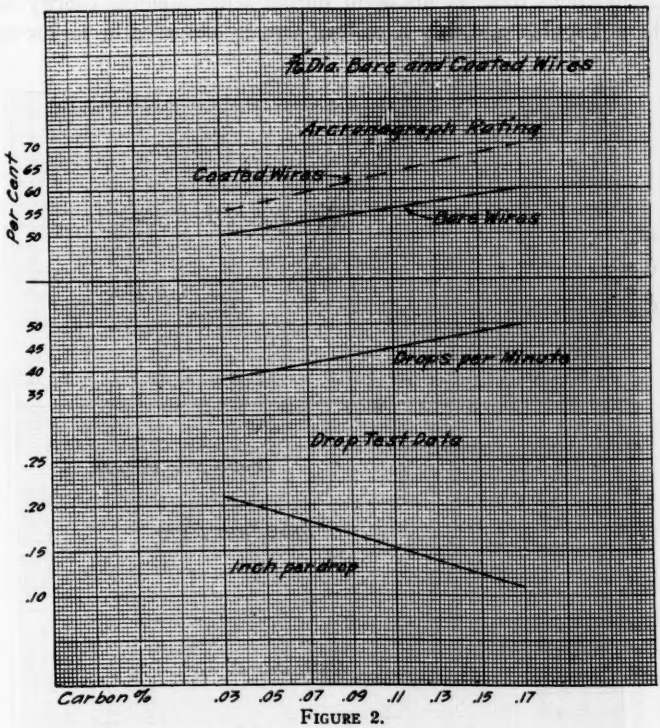


FIGURE 2.

To the investigators, the charts obtained by recording the results of drop deposition tests had a definite meaning in terms of electrode performance. This was later proven to be a fact. Analyzing a typical ammeter record of a bare wire electrode drop deposition (Figure 4), the following interpretation is given. During the formation period there exists pure electric arc of relatively high, constant potential with a corresponding low current density. Dur-

ing the whirling (transfer) period the potential decreases while the current density increases until the instant of short circuit when the elongated drop makes contact with the base metal, while still adhering by its neck to the electrode. Then there exists a minimum potential and a maximum current density. According to the oscillograms these events occur during actual welding exactly as here described and they have been actually observed by means of

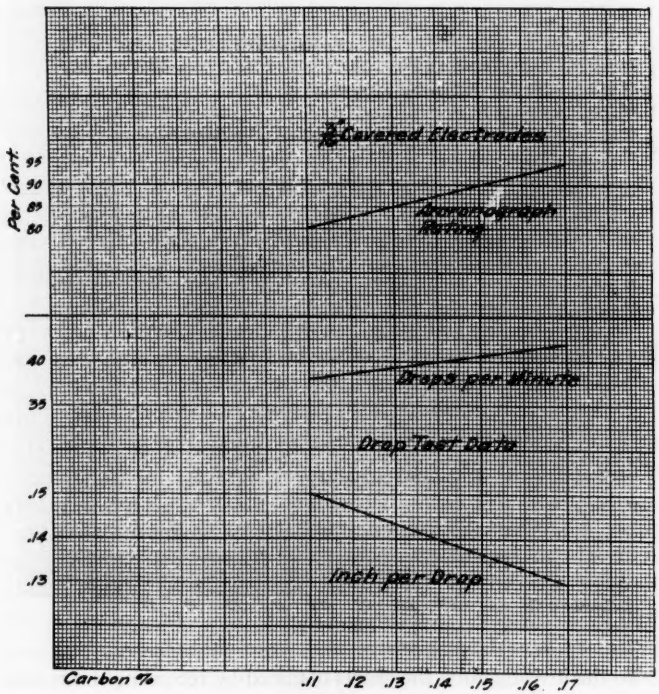


FIGURE 3.

the stroboscope. Of course, during actual welding the duration in time of each period is greatly shortened due to the manifold increase in frequency of the drops; however, each phase still exists and the meaning of this existence is as follows:

BRAND	WELD TESTS Series I U.S.Lbs./sq.in.	WELD TESTS Series II U.S.Lbs./sq.in.	C %	Arcronograph Rating, %	REMARKS	MAGNETIC ANALYSIS REF.
A-1	68000		.11	85	Note 1	Uniform
A-2	70000		.11	90	" 1	"
B-1	74000		.17	95	" 1	"
B-2	72000 Max.	68000		85	" 2	Carbon varies 0.13 to 0.17
B-3	74000 Max.	80000		95	" 2	" " 0.13 to 0.15
C-1	75000		.15	95	" 1	Uniform
C-2	72000		.15	95	" 1	"
C-3	71000		.15	95	" 1	"
C-4	71000		.15	95	" 1	"
D-1	56000		.12	60	" 1	"
D-2	52000		.03	55	" 1	"
D-3	55000		.12	62	" 1	"
D-4	51000		.03	58	" 1	"
E-1	54000		.12	65	" 1	"
E-2	45000 Max.		.07		" 1	Knurled electrode
E-3	61000 Max.	63000 Max.		70	" 2	Carbon varies 0.14 to 0.17
E-4	70000		.14	95	" 1	Uniform
H-1	54000		.14	58	" 1	"
H-2	59000 Max.	58000		60	" 2	Carbon varies 0.12 to 0.14
I	56000 Max.	57000		58	" 2	" " 0.14" 0.17
J	65000 Max.	65000		75	" 2	" " 0.14 "0.16

Note 1 - Series I weld tests gave uniform results. Ultimate strength values given are the average of six specimens.

Note 2 - Series I weld tests did not give uniform results. Series II tests made with electrodes grouped, by Magnetic Analysis, gave uniform results except where noted by "max." after the figures. All values represent the average of six specimens unless otherwise noted.

FIGURE 5.

The formation period is the period of maximum power input; calculating from an actual oscillogram of a bare metal weld it appears, at 18-volt potential and 140 amperes, to be 2520 watts during approximately 6/10 of the existence of a single drop (the formation period). During the remainder of its existence, that is, for 4/10 of the time, the potential is 2 volts and the current is 180 amperes, giving an input of 360 watts; *i.e.*, exactly 1/7 of the power input prevailing during the formation period.

Using the same analysis of a covered electrode of the same core diameter and chemical composition as the first one, the following values are obtained: The duration of the formation period extends over 9/10 of the existence of a single drop, during which time the potential is 35 volts, the current 120 amperes, and the power input 4200 watts. During the short circuit period, lasting but 1/10 of the time, the potential sank to 5 volts, the current rose to 200 amperes, and the power input was 1000 watts, or 1/4.2 of what the power was during the formation period.

The above data were sufficient basis for a series of test welds, using a large variety of electrodes ranging from .03 carbon to .18 carbon. (An excerpt of these tests is tabulated in Figure 5.) Upon computation of the results, the investigators felt that the following deductions were fully justified:

The longer the formation period, the greater is the volume of preheated base metal, assuring good fusion.

The smaller the volume of the individual drops, the better is the ratio between it and the base metal melted during the formation period of each individual drop.

(The ratio between the volume of a single drop and the volume of base metal melted is called the penetration ratio.)

The penetration ratio improves with increasing carbon content, regardless of the surface finish of the electrode; yet from practical considerations, the higher carbon ranges (.14 to .18) have not been found suitable for all purposes of welding.

Having thus established certain facts that govern the performance of an electrode, it was next desirable to develop a practical method for evaluating electrode performance without the use of such costly and delicate instruments as oscillographs and stroboscopes; in other words, to progress from the laboratory to the

test floor. The galvanometer of an oscillograph is capable of responding to the alterations of potential and can record these alterations indirectly by means of photographic films, but the value of the time ratio has to be calculated from the record, using the time curve as the basis of the calculation. Moreover, the record is on an expensive film, the time required for development making it even more costly, thus eliminating the oscillograph as a commercial instrument. A practical instrument, suitable for the evaluation of electrode performance has to conform to the following requirements:

(a) It must be able to differentiate between high voltage and low voltage periods occurring during the existence of each individual drop leaving the tip of the electrode.

(b) It must be able to integrate and record the time ratio between the above named periods and furnish a true, chartered record of the performance.

An electrical relay that would respond to the high voltage period of the arc, but would remain open during the low voltage period appeared to meet these conditions.

Owing to the frequency of deposition of these drops, mechanical relays seemed out of the question, as their inherent inertia is bound to be too great to permit such rapid response.

Attention was next turned to the vacuum tube, which is practically devoid of inertia. The result was:

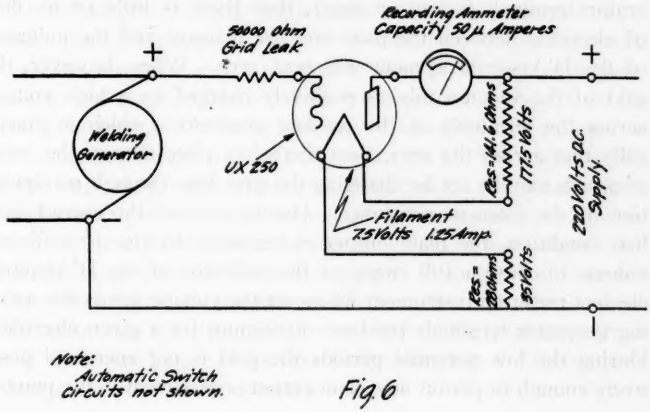


Fig. 6

THE ARCRONOGRAPH.

The arcronograph circuit, schematically presented in Figure 6, has been evolved with the cooperation of Professor G. G. Robinson and Assistant Professor G. Robert Giet, of the U. S. Naval Postgraduate School.

The arcronograph is an electrical instrument that automatically integrates and graphically records the time ratio of the voltage variations of the arc as the successive drops are deposited, thus giving a true record of the electrode performance and hence of the resulting weld. Its operation is as follows:

The filament of the vacuum tube is connected through suitable split resistors to a source of constant potential direct current. The plate of the tube is connected in series with a D'Arsonval element recording meter to the positive side of the above mentioned constant potential, without the use of resistances if the potential of the source is within the range of the tube used. The grid of the tube is connected through a suitable grid leak resistor to the positive terminal of the welding generator. The negative terminal of the welding generator is connected to the negative terminal of the constant potential source already referred to.

The vacuum tube acts as a high speed relay when connected thus: When the grid of the vacuum tube has little or no charge impressed upon it (*i.e.*, when the potential across the welding generator terminals is low or zero), then there is little or no flow of electrons between the plate and the filament and the indicator of the D'Arsonval element will read zero. When, however, the grid of the vacuum tube is positively charged by a high voltage across the terminals of the welding generator (which is practically that across the arc), then there is a plate output, the value of which may be set by changing the grid bias through manipulation of the filament resistance. Having created the correct grid bias condition, the plate output is regulated to rise to sufficient volume to cause a full swing of the indicator of the D'Arsonval element metering instrument whenever the voltage across the welding generator terminals reaches a maximum for a given electrode. During the low potential periods the grid is not energized positively enough to permit any plate output; consequently, the pointer

of the meter seeks to regain the zero position. This pointer, however, has a certain small inertia of its own, which prevents it from following the rapid alterations of the welding generator voltage—it can not make full swings in synchronism with the frequency of high and low potential changes of the arc during welding. Consequently, it assumes a position which is the mathematical mean of the time relationship of the high and low potential periods of the arc. If the strip chart upon which the recording pen of the pointer rests is divided into one hundred parts, then a record of 60 appearing upon the chart means that for 60 per cent of the time elements during welding the pointer tended to swing out fully to the right or the 100 per cent mark (indicating maximum voltage) and during 40 per cent of the time elements it tended to return to zero (marking low or zero potential).

The arcronographs built for practical work embody the simple circuit and principles given above, but in addition are equipped with auxiliary circuits permitting of full automatic operation, starting whenever welding starts, stopping when welding stops, capable of use with either a-c or d-c constant potential sources, etc.

The interpretation of the arcronograph records is quite simple in its main features—each type of electrode has a definite optimum time-ratio for best performance. From the chemical composition of the core metal and the covering, this optimum time-ratio may be quickly ascertained. For a bare electrode of 0.10 per cent carbon the time-ratio for best work is about 56 on the arcronograph. Hence, if an arcronograph chart of a weld made with a bare wire .10 carbon electrode shows no marked divergence from this time-ratio of 56—say the entire record lies between 50 and 61 on the chart—one may rest assured that the resulting weld is as good as can be accomplished with a bare electrode of that composition. In the same way, wash or sul-coated electrodes will usually have an optimum time-ratio or arcronograph rating somewhere between 60 and 75 and the heavily covered electrodes usually should fall between 85 and 95 on the arcronograph. Too short an arc will cause a shifting of the record towards the left on the chart and too long an arc moves the track to the right. An unsteady arc is easily apparent, as are impurities in the electrode, or faulty technique on the part of the operator.

It is entirely possible, from the arcronograph records alone of all the beads making up a complete weld (given the characteristics of the electrodes used), to make a reliable prediction of the soundness of the weld and even of the physical characteristics of the weld metal and its fusion with the base metal. On the other hand, the existence of defects may be detected the instant they occur, thus saving the lost time and labor incident to completing a weld and then by X-ograph discovering such defects and laboriously chipping out sound weld metal down to the defect and rewelding the whole. It is confidently predicted that in the near future no weld of any importance will be made without arcronographs of every bead therein, with the ensuing knowledge of the soundness of the weld, without recourse to expensive, and in some cases, impossible, X-ographs.

The arcronograph also serves as a quick and accurate means of classifying welders according to their ability, of training welders by immediate graphic representation of their faults, and of grading electrodes as to homogeneity and uniformity of structure of the core and the efficacy and uniformity of the covering matrix.

Figure 7 shows a group of photographs pertaining to a butt weld (No. 6) made with a high grade covered electrode. The X-ray of this weld has been interpreted as showing freedom of porosity. The large spots were thought to represent cavities or inclusions between the backing strip and the weld.

The arcronograph chart shows an uninterrupted flow of metal to within about two spaces of the end of the first bead. Here a sharp interruption occurred, resulting in a momentary open circuit condition, which resulted in slag trapping, that is confirmed by the X-ray and by the fracture of the plate. The second bead shows a shortening of the arc for a 1½ to 2-second period, just beyond the center of the bead. The result of the shortened arc is somewhat less penetration than during the rest of the bead. The effect of this was a lack of grain refinement in the metal of the first bead. This phenomenon is also discernible on the photograph of the broken weld. The third bead again shows a local defect, near its beginning. This, too, is discernible in the photograph. This weld was broken with a 20-pound sledge hammer. It took 25

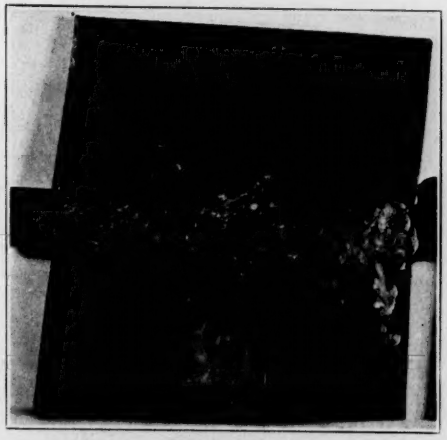


FIGURE 7-A.

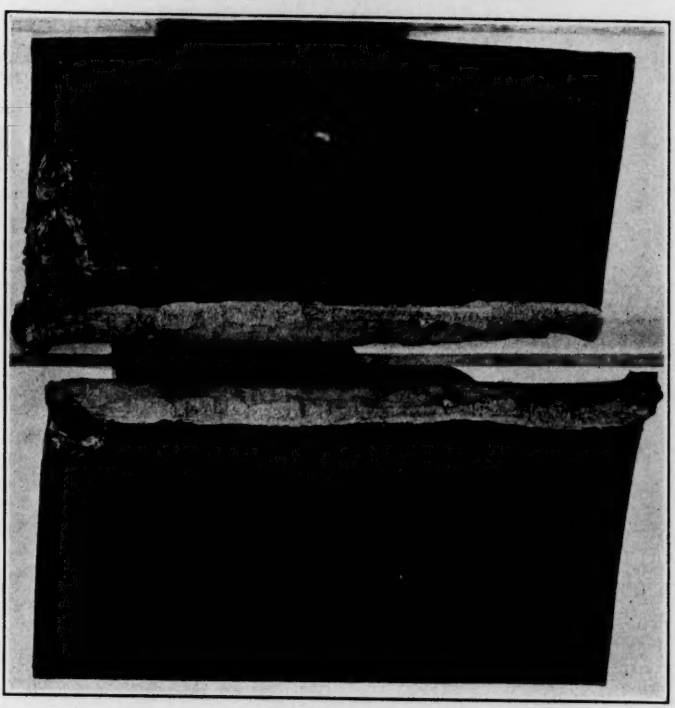
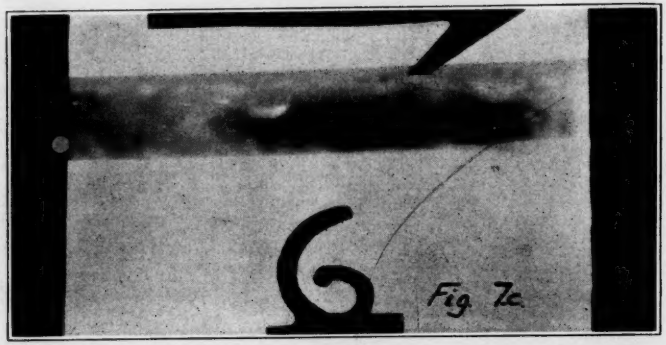


FIGURE 7-B.



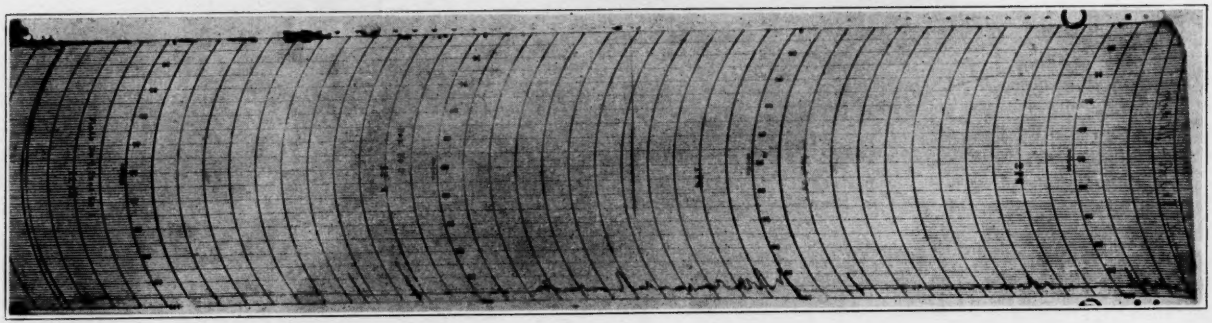


FIGURE 7-D.

FIGURE 7-D.

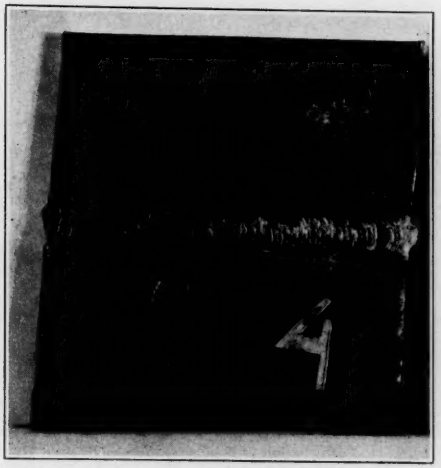


FIGURE 8-A.

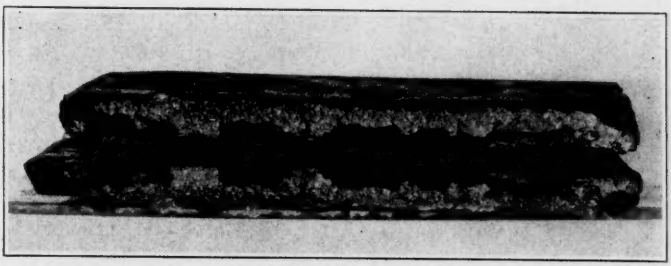
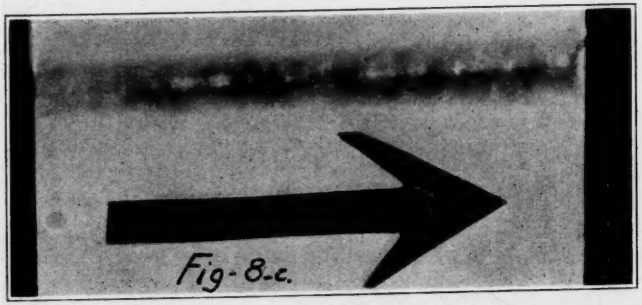


FIGURE 8-B.



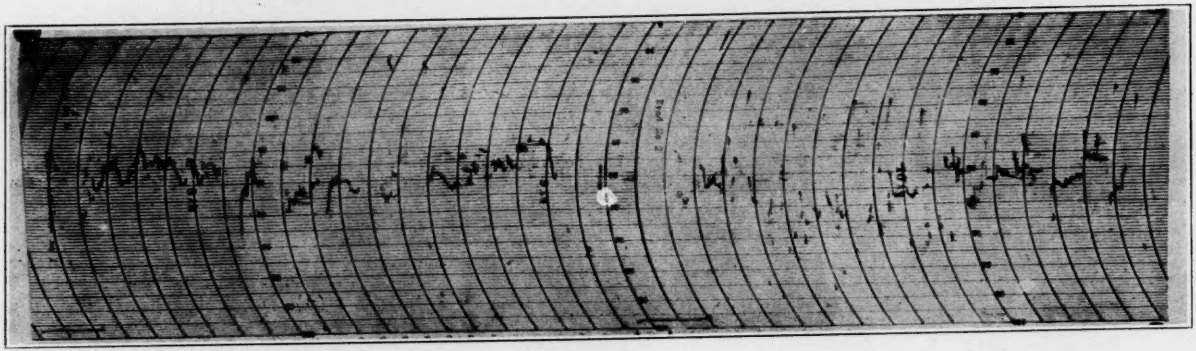


FIGURE 8-D.

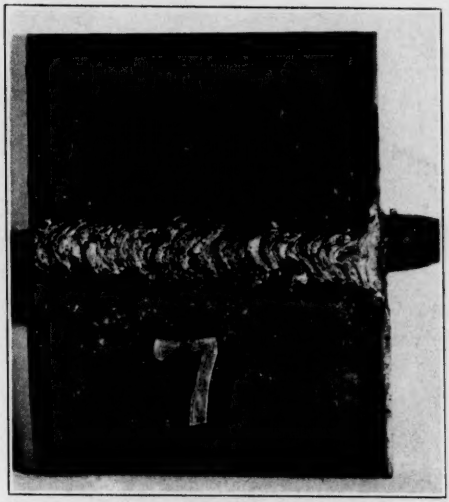


FIGURE 9-A.

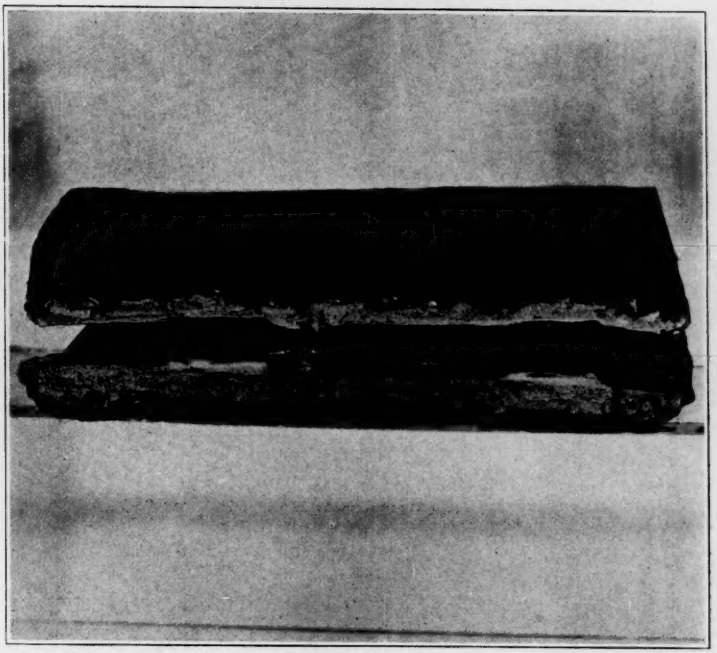
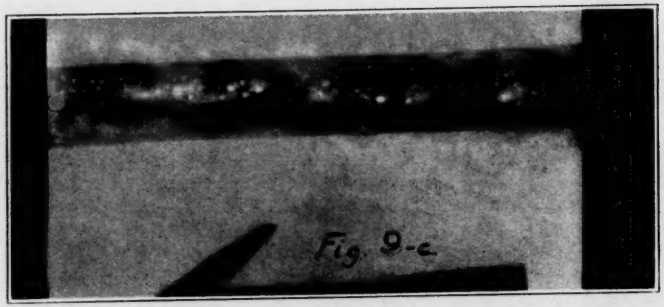


FIGURE 9-B.

FIGURE 8-D.



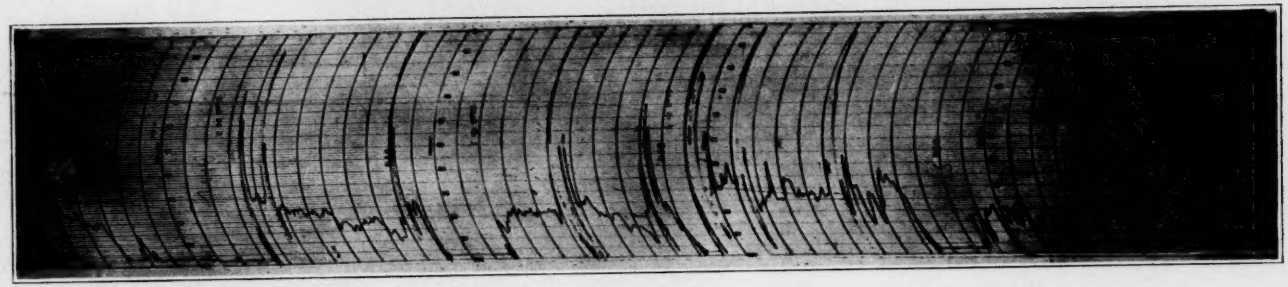


FIGURE 9-D.

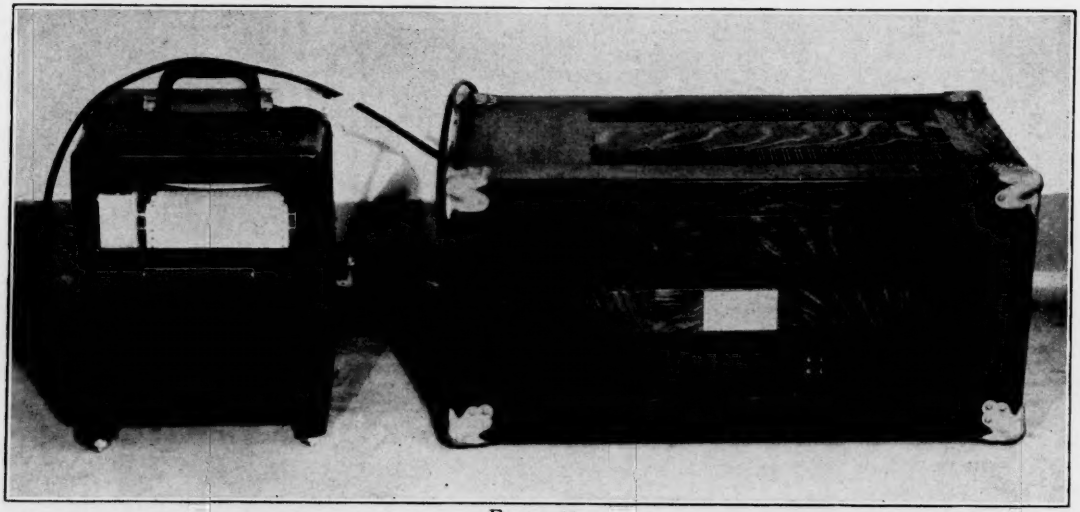


FIGURE 10.

blows to bend the plate 180 degrees. It was then broken in an hydraulic press, by crushing it upon itself.

Figure 8 shows a group of photographs referring to a butt weld made with an inferior grade wash-coated electrode. The welded plate, No. 4, has a normal appearance. The X-ray of this weld is interpreted as showing considerable medium fine porosity, uniformly distributed. It shows lack of penetration along a wide separation line that extends over ¾ of the length of the joint. The broken weld shows that there was no penetration at all for the length mentioned by the X-ray interpreter, but the lack of penetration was not along the separation line (obviously meaning the root-spacing of the weld), but the scarf of the joint remained unfused to the deposited metal. The arcronograph chart shows the reason for this lack of penetration. The arcronograph rating of the first bead is very low (it is below 50 per cent), testifying to the unfavorable penetration ratio that existed during its deposition. The second bead was deposited with a somewhat higher average rating, but there the arc was wild, like when subjected to a magnetic blow; hence, the spongy porosity of the deposit. This weld broke from two blows of the sledge hammer.

Illustration 9 shows a group of photographs pertaining to a butt weld made with an inferior grade covered electrode. This weld is plate No. 7. Its appearance is normal. The X-ray interpretation is as follows: The weld metal is very porous—cavities range from very fine to coarse. They are not uniformly distributed. The arcronograph chart of this weld shows a very disturbed arc condition at about ⅓ of the length of the first bead. This condition is shown to have culminated in a prolonged short circuit period, with a very slow recovery, during which other prolonged short-circuit periods occurred, resulting in lack of fusion. The broken weld shows this condition plainly. The cumulative effects of the broken arc of the first bead are evident on the records of the second, third and fourth beads. A defect of similar nature has occurred toward the end of the third bead—it became cumulative in the fourth bead. The break plainly shows this defect too. The porosity mentioned by the X-ray interpreter was not evident in the weld as shown by the break. It took fifteen blows of the sledge to break this weld.

Photograph 10 shows an arcronograph set, consisting of the instrument case, which houses the vacuum tubes, relays, etc., and of the recorder. Both pieces of equipment are portable and are of a construction that permits handling by persons of ordinary skill, such as welding supervisors or the welders themselves.

CONTROLLED DIRECTIONAL SOLIDIFICATION.

PART 2.

By GEORGE BATTY.*

In the previous article,† castings of relatively simple design were discussed and in each case one feed head was competent to produce the requisite degree of soundness in the casting.

It now becomes necessary to describe the procedure to be adopted in producing castings which, because of their design, demand more than one feed head. In this classification we have gear blank castings which have been produced in large numbers on the "reversal" system which is designed to promote controlled directional solidification.

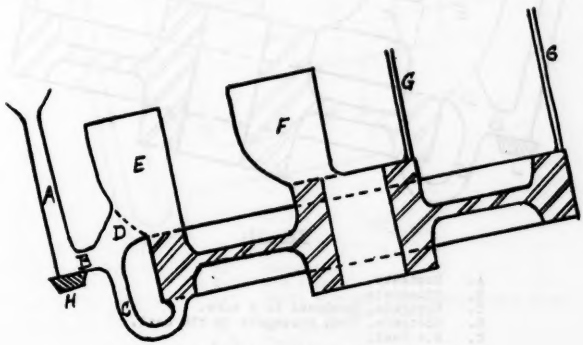


FIG. 14.

A. Downgate.
B. Crossgate.
C. Horngate, produced in a core.
D. Slotgate from crossgate to rim head.
E. Rim head.
F. Hub head.
G,G. Vents from hub and rim.
H. Steel splashplate.

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Gear blanks are, however, so diversified in type that one prescription of procedure would not be adequate for all types. It is therefore proposed to illustrate the procedure adopted on two different types of gear blank castings.

The first, indicated on Figure 14, has a relatively shallow but thick rim and a deep heavy hub, the rim and hub being connected by a plate.

Unless the hub is of exceptionally heavy section it is regularly practicable to limit the gating as shown on Figure 14, but if the hub is of a very heavy section it becomes advisable to carry a cross gate from the rim riser to the hub riser as illustrated on Figure 15.

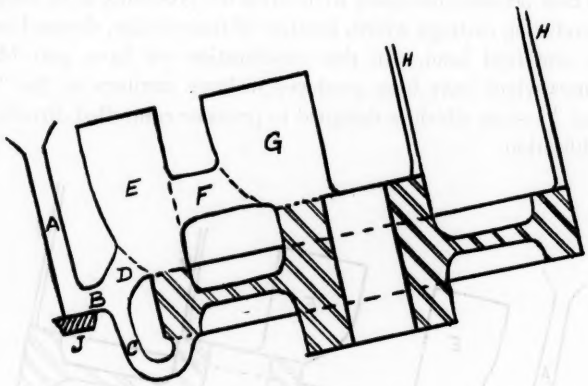


FIG. 15.

A. Downgate.
B. Crossgate.
C. Horngate, produced in a core.
D. Slotgate, from crossgate to rim head.
E. Rim head.
F. Crossgate from rim head to hub head.
G. Hub head.
H.H. Vents from high points of hub and rim.
J. Steel splashplate.

The provision of this cross gate ensures the delivery of hot metal to the riser on the hub and thereby promotes a more favorable temperature gradient at the hub than is attainable by the method illustrated on Figure 14.

A number of gear blanks of this type have been made on the total reversal system as indicated on Figure 16, but the limitations

of equipment in some foundries make the application of such procedure somewhat difficult. It must be remembered, however, that this total reversal system—which was indicated, in relation to a brake drum, on Figure 10 and in relation to a truck wheel on Figure 8 (Part 1), is one which has the greatest capacity for producing controlled directional solidification because of the relation of gates to feed heads, and also presents the advantage of eliminating an isolated hot spot at a location on the casting inimical to internal soundness.

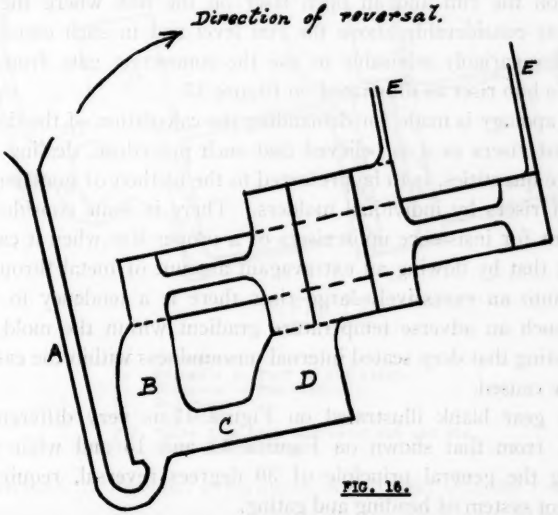


FIG. 16.

A. Downgate.
B. Rim riser.
C. Heavy crossgate connecting rim riser to hub riser.
D. Hub riser.
E.E. Vents.

Reverting to a discussion of the production of a casting as indicated on Figure 14 it should be said that the mold should be inclined at a pouring angle of about 10 degrees, as shown on the figure, and that when the mold is filled the vent or vents should be sealed and the mold reversed through an angle of about 30 degrees, thus having an angle of rest of 20 degrees. When the mold is filled, in the pouring position, the head imposed on the rim of the blank will be almost full, whereas the head on the hub will only

be partially filled. Immediately upon reversal, the height of metal in the rim head decreases and the height of metal in the hub head increases, and, it is, therefore, obvious that the dimensions of the rim head should be such that it will contain, after reversal to the angle of rest, sufficient metal to ensure the proper feeding of the casting. The dimensions of the hub head are also assessed on the basis of the metal which will be contained by the riser cavity after the mold is reversed.

In some cases it has been found advantageous to use a blind riser on the rim and an open riser on the hub where the hub projects considerably above the rim level and in such cases it is almost invariably advisable to use the connecting gate from rim riser to hub riser as illustrated on Figure 15.

No apology is made for demanding the calculation of the dimensions of risers as it is believed that such procedure, dealing with definite quantities, is to be preferred to the method of guessing the size of risers by individual molders. There is some considerable warrant for insistence upon risers of a proper size when it can be shown that by flowing an extravagant amount of metal through a mold into an excessively large riser there is a tendency to produce such an adverse temperature gradient within the mold and the casting that deep seated internal unsoundness within the casting may be caused.

The gear blank illustrated on Figure 17 is very different in design from that shown on Figures 14 and 15 and while preserving the general principle of 30 degrees reversal, requires a different system of heading and gating.

This gear blank has a rim which, as shown on the illustration, has a ratio of depth (face width) to rim thickness of seven to one. It cannot, therefore, be properly fed from a riser imposed only on the edge of the rim and a lumped riser is used, as illustrated, to ensure that a satisfactory temperature gradient be secured in pouring.

The hub of this gear blank is of relatively light section and the spokes are of light box section to produce what appears to be a double-plate gear.

The ingate is led into the root of the lumped riser and the slot gate ensures the delivery of hot metal to the upper levels of the riser in the later stages of the filling of the mold.

It will be seen that the riser on the hub is remote from the ingate and that this riser is, thereby, representative of many of the risers which are imposed on steel castings. We secure an illuminating illustration of the relation which ingate bears to riser on a steel casting by considering the size of the feed heads imposed on the rim and on the hub of the gear blank casting under discussion. As

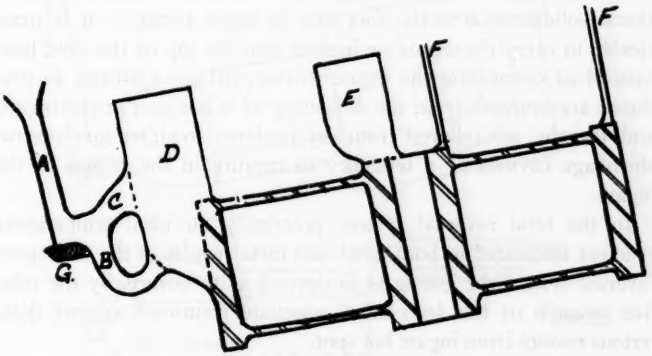


FIG: 17.

A. Downgate.
B. Horngate to root of rim riser.
C. Slotgate to rim riser.
D. Rim riser.
E. Hub riser.
F.F. Vents from high points of hub and rim.
G. Steel splashplate.

determined by repeated experiment, it is found that the riser imposed upon the hub should approximate, as a minimum, 30 per cent of the weight of the hub whereas the riser imposed on the rim is of sufficient size—on this design of gear—if its capacity is equal to 16 to 18 per cent of the volume of rim and spokes. In the rim riser, by its relation to the gate, we have the head of a temperature gradient which ensures adequate feeding from a relatively small amount of metal but in the hub riser we have to provide a reservoir of metal, and of heat, to counteract a local adverse temperature gradient.

The contraction cavity in the rim riser is almost entirely primary pipe, whereas in the hub riser there is usually a shallow primary pipe and a narrow elongated secondary pipe. The rim riser is

either oval or roughly rectangular in section whilst the hub riser should be circular in its main section, necked down obliquely to effect a junction with the face of the hub. This circular section of the riser is the one calculated to conserve temperature—and therefore feeding—to the most satisfactory degree.

One of the most valuable features of the " reversal " system of mold manipulation which is applied to promote controlled directional solidification is the fact that in many instances it is practicable to carry the ingate or ingates into the top of the feed head instead of connecting the ingate to the casting. Castings so produced are immune from the deficiency of a hot spot at the ingate, and, thereby, are relieved from any tendency to either fine internal shrinkage cavities or a tendency to rupture in the region of the ingate.

In the total reversal system practically an ideal temperature gradient is created in both mold and metal whilst in the 30 degree reversal system the gating is so devised as to ensure, by the relative location of the feed head, adequate insurance against deleterious results from ingate hot spot.

Lying between the total reversal and the 30 degree reversal systems is the 100 degree reversal procedure which has been applied to a large number of castings of various types. So far as manipulation of molds on the foundry floor is concerned this 100 degree reversal system is not so easy to apply as the 30 degree reversal, but is applicable to a wide weight-range of castings if a crane is available for mold manipulation.

The example chosen for illustration of the 100 degree reversal system is a cross-head, as shown on Figure 18.

In the 100 degree reversal system, as in the total reversal system (180 degrees) the ingate or ingates lead into what is, in the position of rest, the top of the feed head.

The cross-head chosen to illustrate this particular variant of the reversal system involves also the use of external chills applied to heavy sections. These chills are semi-annular in form and are, preferably, mounted in the core rather than in the mold. The reason for this provision is that in the normal progress of contraction of the casting these chills will remain in contact with the cast metal and continue to absorb heat from the metal, whereas if

they are located in the mold the normal contraction of the casting would, at an early time in the period of solid contraction, withdraw the cast metal from contact with the chills.

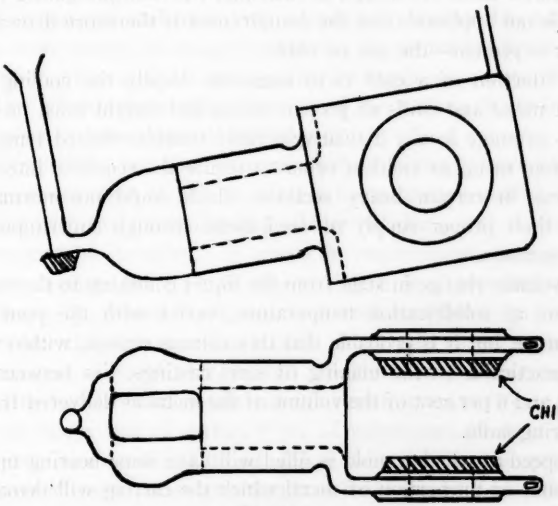


FIG. 18.

Upper shows casting in pouring position.
Lower shows, more completely, gating, heading and chilling.

The mold is located for pouring at an angle of about 10 degrees as shown on the upper illustration of the casting (Figure 18) and as soon as pouring is completed the vents are sealed and the casting reversed immediately through an angle of about 30 degrees. This brings the feed heads to a superior position so that feeding may proceed by simple gravitation and, as soon as practicable, the mold is further reversed through 70 degrees, completing the 100 degree reversal and bringing the feed heads directly over the casting.

It is fundamental, in good steel foundry practice, to locate feed heads on the heaviest sections and the writer believes that it is equally fundamental to gate into heavy sections. In the castings already described, and briefly discussed, the design is such that both these fundamentals may be observed but it is recognized that

in many types of castings heavy sections, relatively remote from each other, are connected by lighter sections. In some cases this difficulty may be overcome by multiple gating into heavy sections but in other cases the design is such that the multiple gating procedure is not applicable and the foundryman is therefore driven to another expedient—the use of chills.

The function of a chill is to accelerate locally the cooling of the cast metal and chills of proper design and weight must be applied to promote locally a relatively rapid transference of temperature from metal to mold in order to secure the requisite internal soundness in certain heavy sections which could not normally receive their proper supply of feed metal through superimposed lighter sections.

The volume change in steel from the liquid condition to the solid condition, at solidification temperature, varies with the pouring temperature, but it is probable that this volume change, within the range practicable in the making of steel castings, lies between 4 per cent and 6 per cent of the volume of the metal as delivered from the pouring ladle.

The speed at which a mold is filled will have some bearing upon the amount or proportion of metal which the casting will demand from the feed heads in order to promote complete internal soundness, and the writer attaches considerable importance to the rate of filling a mold in relation to the details of design of a casting.

In the operation of the various reversal systems of mold manipulation which have been described, it is believed advisable to use metal as hot as is practicable—in relation to the capacity of the molding materials to resist the thermal and physical attacks of the metal—and to pour the casting as slowly as is practicable with the object of creating the greatest possible temperature gradient in both mold and metal.

In castings of complex design, where various heavy sections have to receive their metal through the thinner sections of the casting, and where it is devised to promote soundness by chilling these heavy sections located remote from the ingate, it is considered advisable to pour the casting quickly so that the least possible adverse temperature gradient in both mold and metal be created in the act of filling the mold.

In general terms, two types of chills are available to promote soundness in relatively heavy sections which are isolated from proper feed supply by interposed light sections. These two types of chills are the external chill and the internal or " cast-in " chill.

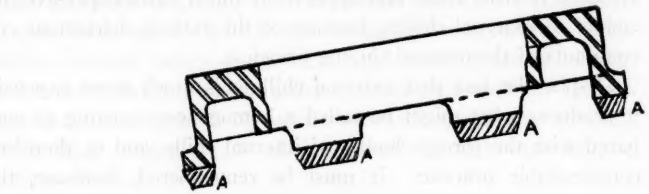
The internal chill is a very simple and inexpensive expedient, but, with steadily widening experience, the writer has progressively replaced internal chills and applied the much more expensive procedure of external chilling because of the various deleterious concomitants of the internal chilling principle.

Despite the fact that external chilling is much more expensive it produces what might be called a homogeneous casting as compared with the foreign bodies of internal chills, and is, therefore, commendable practice. It must be remembered, however, that some castings are of such design that it is almost impossible to promote the desirable degree of internal soundness by the use of external chills because these chills, in certain cases, augment the resistance of mold or core and would cause the rupture of the casting by resistance to normal solid contraction. A case in point is the heavy seat of certain types of valves and the only available remedy is a modification of design whereby feed metal may be delivered from the exterior surfaces of the valve body to the seat through a feeding pad.

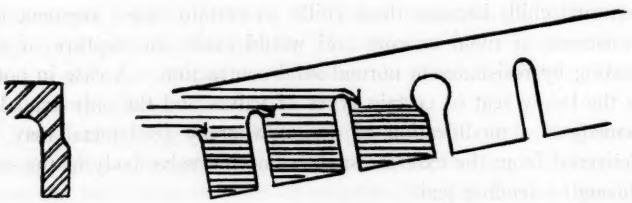
Objections are raised, both by machinists and designers, to the application of this sensible expedient and as a result many foundrymen have been compelled to continue the use of internal chills in such locations after they have been convinced of the danger attendant upon the use of such material.

An example of the application of external chills to isolated heavy sections is illustrated on Figure 19 which shows the partial reversal principle of pouring applied to a casting of non-uniform design. The main illustration shows the casting in the pouring position and the detail of the inner ring is shown with flow lines to indicate the value of pouring such a casting " on the bank." So far as the inner ring is concerned—this ring being deeply slotted by cores—it can be seen that in the process of filling the mold each projection is filled with metal successively and the metal within the recess remains relatively still and undisturbed by the flow of the succeeding metal over it.

The metal within each cavity promptly comes to rest and is cooled by contact with the mold while metal continues to flow above and heat the upper part of the mold so that a slightly enlarged section is competently fed, after the mold is reversed, through a slightly restricted section by reason of the creation of a locally favorable temperature gradient in both mold and metal.



A.A. External chills.



Section

Inner ring. Flow of metal in mold indicated.

FIG. 19.

The disparity of section existent between the outer ring and the heavy feet dependent upon it is such that external chills are necessary to ensure the soundness of both the heavy feet and the lighter section imposed above them. The chills are devised to promote accelerated cooling in the liquid and solidification phases so that the " feed demand " made by the heavy sections is so prompt or rapid as to be adequately met by the capacity of the superimposed lighter section to remain fluid and preserve its ability to conduct, by gravitation, the requisite amount of feed metal to the heavy sections.

Engineers and designers might consider this casting illustrated on Figure 19 to be a relatively simple foundry proposition, but the

castings are machined practically all over, must be spotless in the machined condition and free from any internal cavities that might lead to depression of contact surfaces in service. The writer is able to say that until the principles of controlled directional solidification were applied in the production of this casting it was not uniformly produced to the satisfaction of the consumer.

Another example of the simple application of external chills is illustrated on Figure 20 which shows a part of a long boom casting. The tendency to tear or crack at the junction of the cross members with the side members was, to a large extent, due to the great length of the casting and the consequent concentration of stress manifesting itself at a location which is temporarily weak because it is, temporarily, at a higher temperature than other parts of the casting.

The radiused junctions of cross webs and side members inevitably involves a concentration of metal and, therefore, of heat. Because of this concentration of metal there would, inevitably, be a tendency to the formation of an internal shrinkage cavity unless chills were used. Feed heads above each concentration of metal are impracticable because they would further increase the temperature difference and promote the tendency to cracking or tearing as a result of normal mold resistance.

The chills must be of proper design if they are to achieve the devised object and as there is not, at the present time, any established formula for the calculation of the weight of chill to be imposed an attempt was made to arrive only at a suitable general shape to avoid setting up a sharp line of demarcation between chilled and unchilled portions. A badly designed chill will sometimes merely alter the location of a rupture.

In the case under discussion the width of the chill face was determined by striking lines at an angle of 45 degrees from the mid-line of the cross web as shown on a detail of Figure 20. Then, a maximum thickness of chill equal to one and one-half times the thickness of the side member was decided upon and the three points connected by straight lines to define the section of chill. This type of chill is simple to produce and has proved satisfactory in service, promoting the requisite degree of selective heat absorption

from the casting and avoiding any sharp line or demarcation between the chilled and unchilled portions of the casting.

Whilst it may not be absolutely correct it appears to be adequate in practice and promotes the requisite degree of control in solidification to produce satisfactory and serviceable castings without recourse to the expedient of welding externally evident defects.

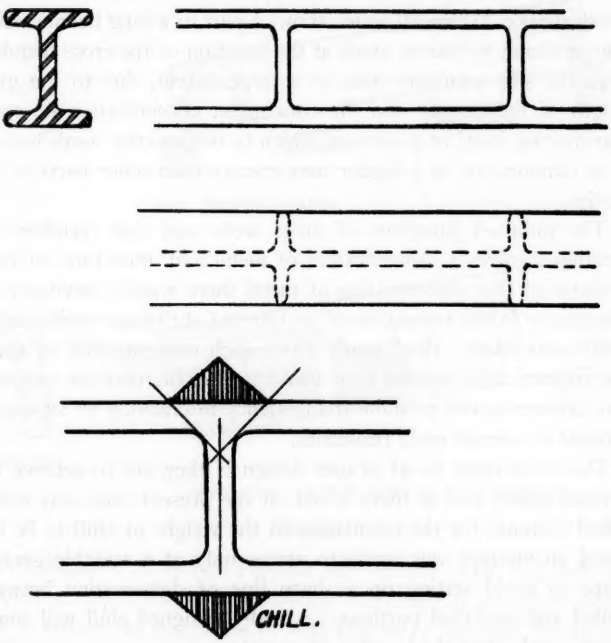


FIG. 20.

Internal chills have certain deficiencies which will not be dwelt upon at length in this paper. It is sufficient here to say that internal chills or even chaplets may promote internal tears and also gas cavities, both of which are deleterious to steel castings.

In the foregoing pages the castings under discussion have been of such dimensions as are regularly produced in molding flasks, the molds being subject to manipulation to promote desirable

conditions for the quiet introduction of metal into the mold, produce a favorable temperature gradient in both mold and metal and, subsequently, to bring the risers or feed heads to the requisite superior position in order that gravitational feeding may proceed uninterruptedly.

Large castings which are made " in the floor " cannot be treated in a similar manner and the promotion of controlled directional solidification therefore becomes, insofar as the design will permit, a matter of correct gating, heading, chilling and pouring procedure. The experience gained in the operation of the reversal systems materially assists in devising such correct procedure for castings made in the floor.

The design of a casting, as well as the type of service which the casting will have to perform, is important in arriving at the size of feed heads. Castings of massive sections, where the ratio of mass to area of surface in contact with mold and core is large, must be provided with a larger reservoir of feed metal than lighter sectioned castings where the ratio of mass to area of contact is small. In the actual process of pouring a casting of relatively light section the amount of liquid contraction achieved during pouring is appreciably greater than that which occurs in the pouring of a casting of heavy section. Also, the rate of solidification is progressively slower as section thickness increases. It is therefore obvious that the light sectioned casting makes a much more prompt feed demand than does the heavy section casting, and can adequately be fed by a smaller proportion of feed metal superimposed as heads or risers.

Such castings as gears, valve bodies and return bends require a larger proportion of feed metal than do ordinary machinery castings because it is absolutely essential that the heads on gears and pressure castings contain not only the whole of the well-defined contraction cavities known as pipe but also contain the loose structure which occurs immediately below the visible pipe. This looseness of structure may not be apparent upon machining but either pressure tests, in the case of pressure castings, or actual service in the case of gears, will demonstrate that this area of loosely compacted crystals is not fully serviceable.

The matter of design is the ground whereon steel founders and designers should meet in order to arrive at conclusions to their mutual advantage and the author would say that he appears to have been particularly fortunate in his contact with designers. Such fortune is not invariably the case and the individual whom the writer considers the most competent steel foundryman of his acquaintance was recently subjected to the comment "That's out," in response to practically every suggestion he made to a designer for modifications of a design which was a metallurgical monstrosity.

As designers and engineers come to know more about the behavior of steel in its changes from the liquid to the cold solid condition they will appreciate the explanations of competent steel foundrymen instead of assuming that such explanations are excuses born of ineptitude or inefficiency.

The designers nowadays appear to be cooperating wholeheartedly with the maker of weldings and, contrary to the opinion of many steel foundrymen, the writer believes that the advent of weldings as a strong competitor of steel castings is ultimately going to react in favor of the steel foundryman if only by reason of the conversion of present designers and the raising of a new brood who will be willing to cooperate with the manufacturer of cast components.

It is conceivable that the splendid advance in welding technique which has been made in the past few years may compound some of the difficulities between designers and makers of steel castings. Certain details of a design may be absolutely essential but may present practically insuperable difficulities in the foundry. By a system of assembling, by welding, several component castings to produce what was originally projected as a single cast piece many of the difficulities will disappear. The partition of the original design should, of course, be made along lines which will ensure that the component castings are of such design as to represent practicable propositions in the foundry.

A consideration of the simple solidification diagrams, Figures 3, 4 and 5 (Part 1), should make it obvious that, without extraneous expedients such as chills, it is not practicable to feed a heavy section through a light section, yet many designs of important steel castings

embody an assumption that it is aways possible to feed heavy sections through light sections.

Figure 21 is a diagram indicating part of a turbine top half cylinder and this design postulates the feeding of the relatively heavy blade cylinder through the lighter walls which produce the steam spaces. By converting the diagram into a series of sections of the actual casting the utter impossibility of adequately feeding the blade barrel will become even more apparent.

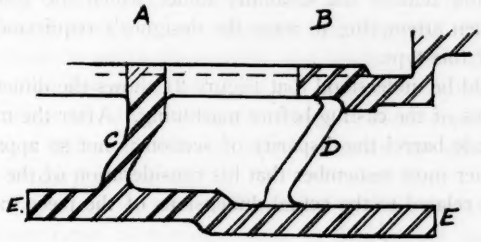


FIG. 21

A. and B. Location of risers
C. and D. Walls or ribs through which feed metal is to be delivered to the blade cylinder.
E.E. Blade cylinder, or barrel.

The wall C and the rib D, shown on Figure 21 constitute inordinately long necks between the feed heads and the blade barrel. Depending upon the factors (*a*) pouring rate (rise of metal in mold per second), (*b*) temperature of metal, and (*c*) inherent fluidity of the metal, the unsoundness of the blade barrel will be slight or acute.

The shrinkage cavity in the blade barrel, resultant upon insufficient feeding, will be located generally about the center of the section of the barrel, inclining upward toward the shell near the crown of the blade cylinder where the walls or ribs connect with the blade barrel.

Being located near the center of the section the defects may not be exposed until the finishing cut for blading is made and, by this time, a great deal of money has been spent on machining.

The remedy for such a condition is to apply heavy feeding pads on the steam space walls to produce broad avenues through which feed metal may be delivered to the blade barrel; but when very close restrictions are placed upon the allowable amount of variation of the dimensions of the steam spaces the removal of these feeding pads becomes a very expensive matter. Either a little more latitude in the acceptance of slight variations in the cross sectional area of the steam space or the incorporation of heavier steam space walls would remove the disability under which the foundryman labors when attempting to meet the designer's requirements on a casting of this type.

It should be understood that Figure 21 shows the dimensions of the sections of the casting before machining. After the machining of the blade barrel the disparity of section is not so apparent but the designer must remember that his consideration of the situation should be related to the actual dimensions of the piece in the cast condition.

It might be argued that turbine cylinders could be cast with the joint flange uppermost. In some cases this has been done and the isolated heavy sections at the base of the casting in the pouring position made sound by the application of chills; but the expense of producing a casting in this way, as against production on the regular or customary method of "flange down," is very great and tends to rule out of consideration such method when contracts are let to the "lowest reputable bidder."

As a digression, it may here be said that it might be a very good thing for many of the parties concerned if Government Departments set up authorities to pronounce upon the advisability of accepting castings which are made to meet the price rather than to meet the service conditions. Briefly, a Technical Acceptability Authority.

In briefly discussing the turbine cylinder no mention was made of the heavy joint flange and, lest some question should arise as to the feeding of this disproportionately heavy section it may be stated that this part of the casting is customarily fed by blind risers. These, however, may not be fully efficient unless a proper temperature gradient is produced at each riser-location by gating into the blind risers.

When the joint flange is so massive that it is considered expedient, despite the additional trouble and expense, to mold the casting with the flange uppermost it becomes a simple matter also to provide feed heads on the blade barrel which will ensure its soundness.

All steel castings, except the most simple forms, such as rings or plates, must necessarily embody some inequalities of section. The junctions of ribs or webs with a plate must be radiused—the foundryman would be the first to protest if they were not—and these radiused junctions are concentrations of metal. Potentially they are places at which the casting may develop either an internal or an external defect but in most cases this type of inequality of section creates no difficulty in the foundry, local acceleration of solidification and mold relieving being achieved by what are now common foundry practices.

In this paper the writer has illustrated by diagrams only a few of the many types of castings, made in flasks, than can be produced most economically on the " reversal " system of mold manipulation, but it is conceded that mold manipulation is limited to certain types and sizes of castings.

The concept of controlled directional solidification must find its most general practical application through the designer and as designs are evolved which accord with the fundamental " big end up " of ingot practice sounder and more serviceable castings will be produced. Admittedly it is not possible to design all complex castings on the general definition " tapered, big end up," but much can be done by the designer to promote more adequate potentialities for the production of internally sound castings. The steel founder will, by carefully appraised gating, heading, chilling, pouring, mold manipulation, and control of temperature and fluidity of metal, add to his established art and practice the virtues of Controlled Directional Solidification.

THE PICKLING OF STEEL CASTINGS.

By C. W. Briggs* and R. A. Gezelius.*

REVIEW OF PREVIOUS WORK.

For many years attention has been directed to the embrittling of steel by acid, as encountered for example in the cleaning of surfaces prior to machining or the application of protective coatings. There has also been considerable discussion as to whether the cracks often found in pickled steel castings are caused, or merely uncovered, by the pickling operation. There is nothing in the literature which shows definitely the relative effects of the various pickling methods, but the results of several series of experiments dealing with the problem have been published.

The early experiments of Johnson (1),† in 1875, were followed by those of Cailletet (2), Ledebur (3), Hughes (4), Heyn (7), Andrew (12), Coulson (15), and Treischel (19). All of these workers pointed out the fact that the brittleness encountered in acid pickling is due not to attack by the acid but to the occlusion of hydrogen by the iron or steel.

Charpy and Bonnerot (11) and Fuller (16) observed that it was the atomic or nascent hydrogen liberated by the pickling operation that was responsible for the embrittlement.

Ledebur (5), Roberts-Austen (6), Burgess and Engle (8), Longmuir (10), Thompson and Mahlman (17), and Watts and Fleckenstein (18), conducted experiments on electrolytic and chemical pickling with various acids under different conditions.

Stromeyer (9), Merica (13), and Parr (14) studied the effect of pickling in alkaline solutions and concluded that absorbed hydrogen was the cause of the embrittlement found.

Langdon and Grossman (21) conducted a rather complete study of the effects of pickling on plain carbon steel rods. The results obtained in this investigation may be summarized as follows:

* Division of Physical Metallurgy, Naval Research Laboratory.
† Numeral refers to articles included in the bibliography.

1. Steel is rendered increasingly brittle with increasing carbon content up to about 0.54 per cent carbon.

2. Brittleness caused by pickling is greatest for steel that has received the greatest amount of cold work.

3. Increasing the temperature of the pickling bath increases the amount of embrittlement up to 50 degrees C. (122 degrees F.). An increase in temperature above 50 degrees C. does not increase the embrittlement appreciably.

4. The brittleness increases with the time of immersion in the pickling bath. This increase is most marked up to 5 minutes' immersion, after which the increase in brittleness is more gradual.

5. Pickling in sodium acid sulphate (niter cake), hydrochloric acid, or hydrofluoric acid produces practically the same embrittling effects as in sulphuric acid of equivalent acid concentration.

6. Electrolytic pickling causes about the same degree of brittleness as is produced by simple immersion in the same acid for an equal period of time.

Williams and Homerberg (22) investigated the penetration of iron by hydrogen in electrolyzed hot caustic solutions. They found that the rate of penetration increased rapidly as the load was increased up to the yield point but stressing beyond the yield point did not appear to have any further effect upon the penetration.

Pfeil (24) was the first investigator to determine the effects of pickling upon the tensile properties of iron. He divided the experimental work of his study into three sections:

(1) Tests on iron in the normal finely crystalline condition,

(2) Tests on single crystals of iron, and

(3) Tests on the boundary between two large crystals.

The tensile tests were carried out while the test pieces were still immersed in the acid as ferrous metals recover their normal properties on standing. The material used was hydrogen purified carbon steel and it was pickled electrolytically.

Finely crystalline aggregates tested during pickling at 25 degrees C. (77 degrees F.) showed a decrease in tensile strength of 9 per cent, while the elongation was only one-sixth of that obtained in a normal test. The specimens broke suddenly as if made from a hard brittle material with a fracture similar to that obtained when metals are broken at temperatures near their melting point, *i.e.*, a fracture that passes entirely between the crystals (intercrystalline).

As the temperature is raised from 30 degrees to 50 degrees C. (86 to 122 degrees F.) the elongation increases and the fracture changes from intercrystalline to transcrystalline. The specimens showed many cracks at right angles to the length of the specimen. Near the fracture the cracks had opened up under the influence of the stress and the fracture itself occurred in the position of the greatest crack.

From the results of the experiments on single crystals and on the boundaries between two large crystals, Pfeil concluded that hydrogen has a remarkable weakening effect on the intercrystalline boundary and that in addition to its effect on the boundaries, hydrogen decreases the cohesion across the cubic cleavage planes.

Pfeil also found that unless pickling was continued during the stressing the effect of the hydrogen was very slight. He pointed out that because of this fact the tensile test is of little value in investigating failures for which occluded hydrogen is thought responsible. As other investigators have shown that slight heating or cold work drives off occluded hydrogen, Pfeil attributes the failure of the tensile test to indicate the effects of hydrogen to the fact that in the early stages of the tensile test the hydrogen is driven off and the normal properties restored.

H. Sutton (25, 26) studied the embrittling effect of various methods of pickling and substantiated previous findings. He also found that the addition of certain organic substances retarded the attack of the acid upon the steel, but that these organic substances or colloids did not prevent embrittlement although certain compounds, notably pyridine and quinoline, did decrease it appreciably.

Recently Slater (42) has completed an investigation on the effects of pickling on the properties of carbon steels and his observations are in substantial agreement with those of other investigators.

In his first experiment Slater studied the embrittling effects resulting from the immersion of annealed wires for different lengths of time in sulphuric acid. He also varied the strength of the acid and the pickling temperature. The data showed that embrittlement begins as soon as the wires are placed in the pickling solution and that the rate of embrittlement is especially rapid in the first few minutes. As the temperature and the concentration of the acid increase the initial rate of the embrittlement increases.

However, the embrittlement is practically the same regardless of the acid concentration or temperature at the end of an hour. The carbon content of the wire sample does not appear to have any appreciable effect on the rate of embrittlement. In all cases the wires became completely embrittled before the scale had been removed.

In the second experiment Slater studied the embrittlement found in hard-drawn wires pickled in 2 per cent sulphuric acid at 20 degrees C. (68 degrees F.) for varying times. The hard-drawn wires were embrittled much more rapidly than the annealed wires.

A study was then made of the effect of pickling in hydrochloric acid and in nitric acid. With a 20 per cent hydrochloric acid pickle at 20 degrees C. the rate of embrittlement is approximately the same as that produced by a 5 per cent sulphuric acid solution at 20 degrees C. Nitric acid causes a slightly more rapid deterioration.

A study of the action of inhibitors on the embrittlement of wires was also undertaken. It was found that the rate of deterioration is lessened by the addition of an inhibitor to the pickling solution. The time of immersion necessary for the complete removal of scale is, however, slightly increased.

Slater then proceeded to study the effect of pickling on the notched-bar impact value of carbon steel. Izod test pieces were pickled in 20 per cent sulphuric acid solution for 2 hours at 15 degrees C. and tested immediately. An increase in notched bar impact value occurred in each instance after pickling. This increase is somewhat variable and bears no relationship to the carbon content of the specimen.

Slater also made Brinell hardness tests. The steels were tested in the normalized and hardened condition after chemical and electrolytic pickling. With chemical pickling no change in hardness could be detected but by electrolytic pickling as cathode a small increase was obtained.

THE PHYSICAL CHEMISTRY OF PICKLING.

Condition of Material to be Pickled. It has been shown by Pfeil (27) that iron or steel that is heated acquires a coating of scale. This scale consists of layers of oxide which decrease in

oxygen content from the exposed surface down to the layer immediately in contact with the metal. The nature of these layers and the extent of their development depends on the furnace atmosphere and the time and temperature of exposure. Winterbottom (28) noted that a scale coating formed in one day at 900 degrees C. (1652 degrees F.) consisted of three layers: an outer ferric oxide layer forming about 2 per cent of the total thickness, an intermediate layer of magnetite comprising about 18 per cent of the total thickness, and an inner layer of ferrous oxide amounting to approximately 80 per cent of the thickness. The overall thickness of the scale was of the order of 0.16 inches.

Scale formed at temperatures below 575 degrees C. (1067 degrees F.), the temperature of the Fe—Fe_3O_4 eutectoid separation, will consist of only two phases, magnetite (Fe_3O_4) and ferric oxide (Fe_2O_3). At higher temperatures the ferrous oxide (FeO) phase appears and as the temperature increases the scale thickness increases proportionately in the ferrous oxide content.

Dunn (29) has shown that, theoretically, the formation of scale is a parabolic function of the time of scaling. However, a complication arises in the theoretical explanations of the disposition and proportions of the scale layers in the form of cracking of the scale during its formation. This cracking permits diffusion of oxygen from the crack and thus a departure is made from the parabolic law.

A deficiency of oxygen in the atmosphere producing scaling would result first in a reduction in the rate of scaling and progressively in the suppression of the outer oxygen rich layers until eventually non-scaling conditions were reached.

One other point in scale formation was brought out by Pfeil (31). He pointed out that the constitution of scale not only varied with the temperature at which it was produced, but that it was also affected by the rate of cooling. In slowly cooled material the inner scale layer dissolves in acid with a much greater rate than does a rapidly cooled material. The change in rate of solution with rate of cooling appears to be due to the eutectoid transformation—ferrous phase of iron and magnetite.

Theories Proposed. Several theories have been proposed to explain the removal of scale during pickling. The theory having

the most popular following is that the acid dissolves the scale; however, the observed facts lead one to believe that the entire story has not been told as it is common knowledge that a scale sludge accumulates in pickling tanks in the course of working. Edwards (23), Chappel and Ely (39), and others have maintained that scale is negligibly attacked by the acid, but that the vigorous action of the acid on the underlying steel, to which access is gained through cracks and pores, leads to mechanical bursting-off of the scale layers. This outlook also lacks completeness as no allowance is made for the case when inhibitors are used to reduce the action on the steel and at the same time not lessening the rate of scale removal.

It is Winterbottom's and Reed's (30) opinion that the inner ferrous-oxide layer dissolves in acid comparatively quickly, while the oxygen-rich phases, magnetite and ferric oxide are practically unattacked. Thus, at a scaling temperature of 900 degrees C. (1652 degrees F.), about 80 per cent of the scale is dissolved and the remaining 20 per cent falls from the piece and accumulates as a sludge in the pickling tanks.

It is difficult to discover what occurs in the pickling of low temperature scales. Although these scales are thin, they require a much greater time to pickle than do the thicker ones formed at higher temperatures, a result that is not unexpected since the FeO phase is absent according to the diagram. Hoor (32) explains the theory involved in the pickling of low temperature scales in a very satisfactory way. He shows the conditions that exist at a crack or pore in the scale. Here it can be expected that a cell will be set up in which the oxide scale is cathodic towards the metal. Iron, therefore, will be dissolved anodically as $Fe^{\cdot\cdot}$, and scale will be reduced cathodically to ferrous oxide; the latter is then dissolved in the acid, exposing fresh ferrous oxide for cathode reduction. Thus, only ferrous iron will be found in solution, which Winterbottom and Reed (30) found to be experimentally correct. Since, however, the electrolytic action will be most pronounced near the scale-metal interface, where the internal resistance of the cell is the smallest, the main solution of scale and metal will occur in these regions, thereby an undermining of the scale will set in and it will eventually flake off.

Kinetics of Pickling. Winterbottom and Reed (30), by using a standard material, worked out the pickling times at various temperatures and concentrations of sulphuric and hydrochloric acid and made the following conclusions concerning their experiments:

(1) The mechanism of scale removal is the same in the case of dilute sulphuric and hydrochloric acids and, by inference, the same in the case of any acid forming a soluble ferrous salt.

(2) Provided that over-pickling is avoided, the acid consumption is directly dependent on the type and amount of ferrous oxide phase. That is to say, the fundamental action in pickling is

$$\underset{\text{(solid)}}{FeO} + 2H = Fe^{\cdot\cdot} + H_2O$$

This is a heterogeneous reaction and its rate should, therefore, be dependent on the hydrogen ion activity, the viscosity of the pickling acid, and the diffusion constant.

The rate of pickling is directly proportional to the acid content at a constant temperature, provided that the bulk of acid solution is sufficient to avoid appreciable alteration in concentration during pickling.

The time necessary for removal of scale is dependent on:

(*a*) The temperature and time of formation of the scale.
(*b*) The hydrogen ion activity of the acid solution.
(*c*) The viscosity of the solution.
(*d*) The temperature.
(*e*) The iron salts.
(*f*) The agitation.

Of these, the temperature, both directly and also by its influence on (*b*) and (*c*) has by far the most important effect on the time of pickling a given material.

INHIBITORS.

In general, pickling inhibitors should be used not only for the saving in acid that is likely to be made, but as an insurance against over-pickling and wastage of valuable material.

Physical Chemistry of Inhibitors. Numerous substances do retard the action of free acid on steel and have, therefore, been

suggested for use as inhibitors. Most of the commercial inhibitors are cyclic organic compounds containing at least one atom of nitrogen in the ring, as, for example, pyridine and quinoline. Many such cyclic organic bases show, to a considerable extent, a specific action in retarding the solution of the metal in the acid. This specific effect is probably due to the deposition of the inhibitor as a protective film on the metal or to some action of the inhibitor in retarding the formation of free gaseous hydrogen.

Only a few investigators have studied the mechanism of the action of inhibitors in minimizing the corrosion of metals by dilute acids. Isgarishev and Bergman (33) have observed that certain colloids, for example, gum arabic and gelatin, increase the apparent over-voltage of iron in contact with sulphuric acid. Siverts and Lueg (34) measured the apparent over-voltage of iron in contact with dilute sulphuric acid containing various heterocyclic nitrogen bases, but were unable to establish any general or quantitative relationship between the effect on over-voltage and the inhibiting efficiency. They suggested that the inhibiting action was due to the formation of an inactive film at the surface of the metal, but gave no data to support this hypothesis. Speller and Chappell (35) point out that many of the inhibitors are violent animal poisons and some are known to have a marked effect in certain catalytic processes. They further stated that their observations seem to justify placing the action of inhibitors in the general class known as catalysts. Inhibitors may be considered to act by forming some sort of film over the bare cathodic steel and that this film acts to prevent the ready evolution of hydrogen.

Chappell, Roetheli, and McCarthy (36) measured the effects of quinoline ethiodide in various concentrations and under various conditions upon the rate of evolution of hydrogen from iron and dilute acid and also upon the apparent over-voltage between iron and acid. They found that there was a general parallelism between the retardation of the evolution of hydrogen and the apparent over-voltage when the iron was made cathode in the acid solution. The effect of the inhibitor on the anodic over-voltage was slight and was considered insufficient to account for the inhibiting effect. These investigators concluded that when iron is placed in a dilute acid solution containing an inhibiting base, the inhibitor is set

free at the locally cathodic areas, and the mechanism of inhibitive action is possibly due to the formation of a blanketing layer of discharged inhibitor substance absorbed on the cathodic areas.

Rhodes and Kuhn (37) studied the inhibiting powers of a large number of compounds and concluded that in every case the addition of a specific inhibitor to the acid electrolyte increased the film resistance at the surface of the metal. They also pointed out that there is no quantitative relationship between the inhibiting efficiency of a given substance and its effect upon the true resistance at the interface. They also claimed that from their data it appeared that the absorption of the inhibitor upon the surface of the metal is a necessary condition for inhibiting action, but that the inhibiting action is not due solely to the effect of the absorbed film in increasing the electrical resistance between the metal and the electrolyte. The indications are that the protective action is due to some specific property of the absorbed film.

Studies of the efficiencies of various inhibitors were made by Chappell, Roetheli, and McCarthy (36), Rhodes and Kuhn (37), Speller and Chappell (38), Chappell and Ely (39), and Winterbottom and Reed (30). From the results of their experiments it can be concluded that:

(1) The amount of acid used in dissolving steel is a variable which can be controlled by an inhibitor.

(2) A small amount of acid is wasted in spent pickle.

(3) The practical efficiency of a commercial inhibitor may be estimated from a simple hydrogen evolution test.

(4) The use of an inhibitor increases the pickling time slightly.

(5) Inhibitors should be used in practice if the best procedure is desired.

BEST COMMERCIAL PICKLING PRACTICE.

The following methods of pickling employ the best commercial methods found in the survey of the literature given above. These processes should be technically controlled as to temperature and chemical requirements. Routine tests must be made if the best results are to follow.

HYDROFLUORIC ACID PICKLING.

Use—The primary use of hydrofluoric acid is to remove sand in the deep cored pockets in castings.

Initial Concentration—

Hydrofluoric Acid	7 per cent by volume
Hydrochloric Acid	8.5 per cent by volume
Water	84.5 per cent by volume

Temperature—Should be from 50 degrees to 60 degrees C. (122 degrees to 140 degrees F.) for approximately one hour to obtain the best results. However, good results are obtained when the solution is at room temperature.

Sandblasting—Before pickling, all loose sand should be removed, as otherwise acid would be wasted in dissolving sand that could be removed more economically by sandblasting.

Neutralizing Bath—After pickling, the castings should be washed with water and then placed in a sodium carbonate bath to neutralize the acid remaining.

Inhibitors—As in sulphuric and hydrochloric pickling, an inhibitor should be used in order to minimize the acid attack on the steel.

Embrittlement—Langdon and Grossman (20) showed that pickling in hydrofluoric acid produces practically the same embrittling effects as in sulphuric acid of equivalent concentration.

SULPHURIC ACID PICKLING.

Initial Concentration—A concentration of from 5 to 10 per cent is used most commonly commercially. Suggest using a concentration of 50 grams of H_2SO_4 per litre (4.85 per cent) by taking one part by volume of H_2SO_4 and 26 parts by volume of water (65 pounds per 100 gallons water). Density 1.062.

Temperature—60 degrees to 70 degrees C. (140 degrees to 160 degrees F.). Heat by steam coils or steam injection.

Maintenance—Keep free-acid content up to 50 grams of H_2SO_4 per litre (4.85 per cent, density 1.062) by additions of sulphuric acid as necessary, but on no account add more than a total of 250 pounds of sulphuric acid per 100 gallons of tank volume.

Finishing—Additions should be discontinued when the specific gravity of the liquor reaches 1.17. When the final addition has been made the activity of the liquor should be maintained as far as practicable by raising the temperature and, if possible, the tank should be changed over to work as a preliminary rough pickle. When the activity has fallen below the point where the free-acid content is below 10 grams per litre, the liquor should be discarded. The discarded liquor should approach 10 grams or less of H_2SO_4 per litre, 80 grams per litre of iron, and specific gravity 1.20.

Inhibitor—Inhibitors that are acceptable under the Navy Department Specifications 51–I–2, March 1, 1930, will furnish good results.

Immersion Time—Immersion time is a variable depending on the size of the casting, the time and temperature of heat treatment, and the rate of cooling.

Neutralizing Bath—The bath most commonly used is a 10 per cent sodium hydroxide solution at a temperature of 60 to 80 degress C. (140 degrees–176 degrees F.).

Removal of Absorbed Hydrogen—Steel which is rendered brittle by pickling becomes less brittle upon standing at ordinary temperatures. The recovery is never quite complete, but sections of about ⅜ inch reach a maximum in about 3 days. In air at 100 degrees C. (212 degrees F.) the recovery takes place more rapidly, about 3 per cent of the previous time, while at 150 degrees C. the recovery is about 0.3 per cent of the original time of 3 days. Heating in water at 100 degrees C. (212 degrees F.) is the best practice and maximum recovery occurs in from 2 to 5 minutes on sections up to ⅜ inch.

HYDROCHLORIC ACID PICKLING.

Initial Concentration—A concentration of about 10 per cent is most commonly used. Suggest using a concentration of 100 grams of HCl per litre (9.7 per cent) by taking one part of acid by volume per 2 parts (about) of water (530 pounds per 100 gallons of water). Density 1.045.

Temperature—30 degrees to 40 degrees C. (86 degrees–104 degrees F.). Warm up initially by steam injection or by charging warm material from previous operation. Temperature will then be maintained by the heat of reaction.

Maintenance—Keep free-acid content between 50 and 100 grams of HCl per litre by additions of acid as necessary, but on no account add more than a total of 720 pounds of acid per 100 gallons of tank volume. Additions should be discontinued when the specific gravity of the liquor reaches 1.20.

Finishing—The same remarks apply as for sulphuric acid and the discarded liquors should approach 10 grams per litre of HCl or less, 120 grams per litre of iron, and specific gravity of 1.24.

Inhibitor—Same as for sulphuric acid.

Neutralizing Bath—Same as for sulphuric acid.

Removal of Absorbed Hyrogen—Same as for sulphuric acid.

EXPERIMENTAL RESULTS.

Although the effects of pickling on steel have been studied by many investigators, all of the experimental work has been confined to cold rolled steel in the forms of wire, strip, or rods. Since no data are available on cast steel in either the "as cast" as heat treated conditions, it was deemed advisable to conduct several experiments on this material in order to determine whether or not pickling was responsible for or merely uncovered the cracks which are often found in pickled castings.

It has been previously pointed out by various investigators that pickling is responsible for an embrittling effect caused by atomic hydrogen. Experiments were planned to study this embrittling effect, its extent, and amount in cast steel.

The Effect of Pickling on the Impact Strength of Cast Steel—The studies to determine the effect of pickling on the impact strength of cast steel were conducted on cast steel bars 1 inch $\times$ 1 inch $\times$ 18 inches. These bars were cast eight in a mold both with and without flanges. The bars without flanges should solidify with a minimum of internal strains while the bars with flanges, unable to contract because of the flange, should have considerably more

internal strain. These bars were machined to ¾ inch × ¾ inch × 6 inches, notched for the Charpy impact test, pickled, and tested.

The pickling procedure in all experiments was similar to that used in commercial practice. The bath consisted of a 10 per cent sulphuric acid solution kept at a constant temperature of 65 degrees C. (150 degrees F.) by means of a mercury thermostat which controlled two large incandescent heating bulbs immersed in the solution. The inhibitor used was quinoline ethiodide which has been found to be very efficient. After pickling, the specimens were dipped in a 10 per cent sodium hydroxide solution to neutralize the acid remaining on the specimens and then washed in hot water (75 degrees C. or 167 degrees F.) and dried.

It was thought that cast steel would be subject to considerable change of impact strength by pickling and that the general effect produced would be of an embrittling nature. It was also reasoned that steel cast with high internal stress would show a greater degree of embrittlement than a stress-free steel. Tests were carried out according to the conditions of Table I.

Table I

The Effect of Pickling on the Impact Strength of Cast Steel

Condition	Pickling Treatment	Impact Foot Pounds
Freely Contracting Bars		
As cast	None	23.5
As cast	10% H_2SO_4 at 65°C for 1/2 hr.	47.5
Annealed	None	85.0
Annealed	10% H_2SO_4 at 65°C for 1/2 hr.	100.0
Hindered Contracting Bars. (Bars with flanges)		
As cast	None	38.5
As cast	10% H_2SO_4 at 65°C for 1/2 hr.	28.0
Annealed	None	165.0
Annealed	10% H_2SO_4 at 65°C for 1/2 hr.	103.0

The results were somewhat surprising. In part they showed the same feature of toughening as Slater (42) found in his experiments on hot rolled rods. This feature of toughening was apparent on only the freely contracting series. In the hindered contracting series an embrittling action was noted. It would appear, therefore, that perhaps the condition of the steel is very important in determining its reaction after pickling. By this it is not inferred that the amount of internal stress is the controlling factor, as it can be seen that in the case of the annealed specimens one set became embrittled while the other obtained a certain degree of toughening.

A portion of this work was repeated on Charpy bars machined from regular test coupons. These bars were, of course, free from strain and corresponded to those obtained from the freely contracting bars except that the carbon content was higher and, therefore, higher impact values were obtained.

Several of the bars were tested in the "as cast" condition. The remainder were annealed at 900 degrees C. (1650 degrees F.).

All of the pickling was carried out at 60 degrees C. (140 degrees F.) in 10 per cent sulphuric acid for forty-five minutes. When an inhibitor was desired, a commercial inhibitor was added in an amount equal to 10 per cent of the acid concentration.

Pickling in this case caused an increase in the impact strength similar to that found in the previous experiment and by Slater. The results are listed in Table II.

Table II

The Effect of Pickling on the Impact Strength of Cast Steel

	Foot pounds.
As cast	98
As cast pickled without inhibitor	135
Annealed	186
Annealed pickled without inhibitor	231
Annealed pickled with inhibitor	240

The impact test is of a dynamic nature and does not involve the time factor (often of considerable magnitude) which is found in the tensile, bend, or torsion tests. It is true that dynamic tests will give some measure of the properties of the interstitial solid solution initially formed and perhaps this accounts for the varied results obtained.

It is not desirable to continue experimentation along this line as the test did not strictly represent conditions found in practice, as pickled castings usually fail in tension and not by the application of an impact force.

The Effect of Pickling on Previously Elongated Tensile Specimens—In the study of elongated and pickled tensile specimens the test pieces were prepared from cast coupons. The standard 0.505 inch diameter test specimens were used. One-half of the specimens were placed in a furnace at a temperature of 900 degrees C. (1650 degrees F.); ten minutes were allowed for the specimens to come up to heat. The specimens were kept at heat for 20 minutes and then furnace cooled.

Since all castings have internal casting strains of some magnitude, it was decided that by elongating tensile specimens prior to pickling, an idea as to the stress necessary for marked embrittlement would be obtained. Specimens were elongated 0.5, 1.0, 1.5, and 2.0 per cent in a tensile machine, removed and pickled, and then tested. In elongating, 2.0 per cent was chosen as the maximum, as a casting completely hindered in contraction would be equivalent to only 2.2 per cent. The results of the test are listed in Table III and shown in Figure 1.

Table III

Physical Properties of Elongation and Pickled Tensile Specimens

Treatment	Yield* Point lbs/sq.in.	Tensile* Strength lbs/sq.in.	Elongation %	Red. Area %
"As Cast" Specimens				
No elongation, not pickled	35,666	70,333	21.8	31.1
No elongation, pickled	36,800	70,333	17.6	24.7
Elongated 0.5%, pickled	37,366	70,233	19.6	26.8
Elongated 1.0%, pickled	38,600	69,366	16.5	21.5
Elongated 1.5%, pickled	40,050	70,866	19.0	23.8
Elongated 2.0%, pickled	41,566	70,833	18.4	23.9
Annealed Specimens				
No elongation, not pickled	47,800	71,300	26.9	46.2
No elongation, pickled	51,366	71,000	21.8	28.9
Elongated 0.5%, pickled	47,466	71,800	22.9	30.4
Elongated 1.0%, pickled	47,233	71,400	21.0	28.0
Elongated 1.5%, pickled	47,933	71,666	21.0	26.3
Elongated 2.0%, pickled	47,666	72,533	21.2	26.7

*Averages of three readings.

Carbon	0.23%
Manganese	0.76%
Silicon	0.31%

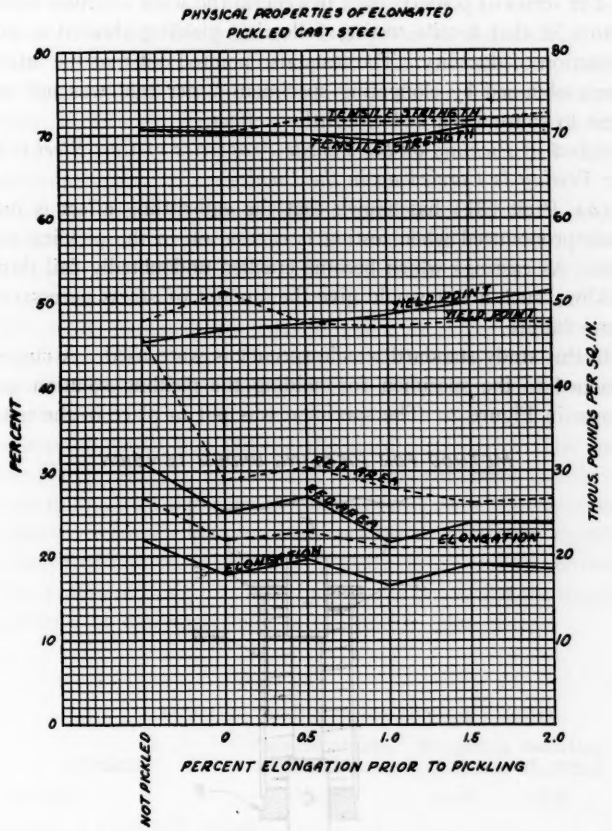


FIGURE 1.

It will be noticed that the magnitude of embrittlement remained the same regardless of the amount of elongation. In fact, specimens that were pickled without elongation showed an embrittling action equal to that of the elongated specimens.

Changes were found to exist in the yield point, the elongation, and the reduction of area. The tests were made approximately three hours after the pickling operation.

The series of tests checked in general the work of other investigators in that tensile testing following pickling showed a slight reduction of ductility. The tests also pointed out that the internal stress obtained by elongating specimens 2 per cent was not sufficient to cause a marked embrittling effect.

Effect of Pickling on the Tensile Properties of Cast Steel When the Testing Is Carried on in the Pickle—

(*a*) Pfeil (31) has shown that the embrittling effect is much more pronounced when testing is carried on in the pickling solution. As castings which become cracked undoubtedly fail during pickling, such a test would give the amount of stress necessary to cause failure.

In this study standard tensile specimens were used. A cup was attached to the specimen for holding the pickling solution as is shown in Figure 2. The specimen was put in place in the tensile

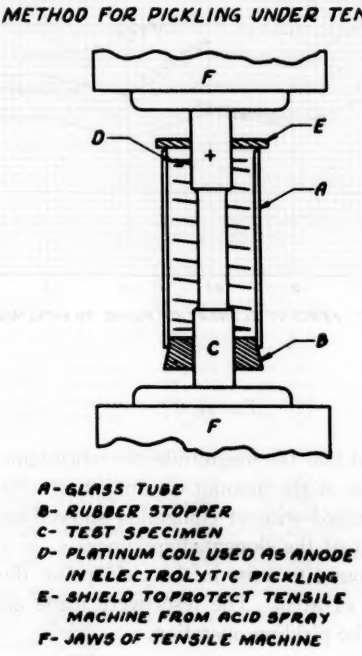


FIGURE 2.

machine and then the acid was poured around the specimen. When chemically pickling, the solution was kept at 65 degrees C. (150 degrees F.) by electrically heating the glass container by means of a nichrome coil around the glass container. In electrolytic pickling, a platinum wire helix was used first as the cathode and then as the anode. The electrolytic pickling was carried on at room temperature.

After the specimen had pickled a predetermined time, which was usually an hour, since Slater (42) and Pfeil (31) had shown that an hour was sufficient for maximum embrittlement, the specimen was tested to failure in the acid.

The results obtained are given in Table IV. The ductility has dropped off considerably. There are no differences in the physical properties obtained when the specimens are pickling either under stress or free of stress, even though the stress used is of a magnitude approximately one-half of the tensile strength. The time element of pickling is important if full embrittlement is desired. This is in line with the work of Slater (42). When the specimen is removed from the pickling bath and tested in air the ductility has increased and the specimen is already on its way to recovery.

The important thing that this study points out is that the internal stress must be extremely high before failure takes place.

Table IV

Effect of Testing in the Pickling Solution

Treatment	Tensile Strgth. lbs./sq.in.	Elongation %	Reduction of area %
Annealed	71,300	26.9	46.2
Pickled 1 hr. at 65°C in 10% H_2SO_4 under tension of 34,000 lbs./sq.in. and tested in acid	71,000	15.5	16.4
Pickled 1 hr. at 65°C in 10% H_2SO_4 and tested in the acid.	70,250	15.3	16.3
Tested in 10% H_2SO_4 at 65°C Testing time 8 minutes	69,850	17.2	20.7
Pickled 1 hr. at 65°C in 10% H_2SO_4 under tension of 34,000 lbs/sq.in. Removed acid & tested. Testing time 10 minutes.	71,700	21.0	25.5

Carbon - 0.23% Manganese - 0.76% Silicon - 0.31%

The effect of pickling upon the yield point was also determined. The specimens used in this test were obtained from the same heat of steel and given a full anneal at 900 degrees C. (1650 degrees F.) prior to testing.

In order to obtain the yield point of a specimen submerged in acid, two arms were attached to the specimen at the punch marks by means of pointed screws similar to those of an extensometer. The arms were supported by a brace attached to an upright of the tensile machine in such a manner that their movement would be parallel to the movement of the specimen during testing. The extensometer was mounted on these arms at a point above the acid solution. The specimens were pickled electrolytically in a bath similar to that shown in Figure 2.

The yield points of the specimens tested in air were also obtained with the extensometer mounted on these arms so that the results would be comparable.

The curves obtained were identical up to the yield point and parallel throughout the remainder of their length. The specimens tested in acid had a higher yield point than those tested in air. The data obtained are given below:

	Yield Point Pounds Per Square Inch
Tested in air	51,400*
Tested under acid	53,750

Effect of Time in Air on the Rate of Recovery from Embrittlement—In studying the recovery from embrittlement the specimens were pickled for one hour, then washed in water and tested in air at room temperature after allowing them to stand in air at room temperature for a predetermined time.

It was noticed in the preceding experiment that the ductility increased considerably as soon as the specimen was taken out of the acid. The rate at which this recovery takes place is of interest and the results as set forth in Table V and Figure 3 show several interesting points. The recovery takes place at a very rapid rate during the first few moments. Previous investigators have shown that in time the material recovers nearly all its ductile properties.

*Average of three specimens.

Table V

Effect of Time in Air on the Rate of Recovery from Embrittlement

Treatment	Time Elapsed in air after pickling*	Tensile Strength lbs./sq.in.	Elongation %	Reduction of Area %
Annealed	-	70,000	30.5	42.5
Tested in 10% H_2SO_4 at 65°C 1 hr.	nil	65,625	12.0	15.7
Pickled 1 hr.-10% H_2SO_4 at 65°C	1 min. 20 sec.	68,450	16.0	17.8
" " "	8 min.	68,700	21.0	22.0
" " "	25 min.	68,950	21.5	22.5
" " "	50 min.	69,050	22.0	25.0
" " "	150 min.	68,600	22.0	25.5
" " "	24 hours	69,100	23.0	26.0

*Includes the time the specimen stood in air at room temperature plus the testing time.

From these results two things become apparent. First, that the embrittling effects produced by pickling are not permanent in cast steel; and, second, the physical properties of a material submerged in acid are very much reduced.

In Figure 4, a comparison can be made between annealed specimen (A) and a specimen that was tested in the pickling solution (B). The embrittling effect in (B) is shown by a lack of reduction of area as compared with (A). The specimens tested in the pickling solutions also exhibit many small cracks. These cracks developed about the time the ultimate tensile strength was reached, just a short time before the specimen broke. As will be noticed, these small cracks are numerous and account for nearly all of the elongation obtained. The break is typical of an embrittled material.

The specimen (C) offers a very interesting example. This specimen was pickled in the acid. The acid was removed with a pipette and water substituted which likewise was removed. Because of haste a very small amount of very dilute acid remained in the bottom of the cup and around the fillet of the specimen. Upon testing, the specimen broke in that portion which was sub-

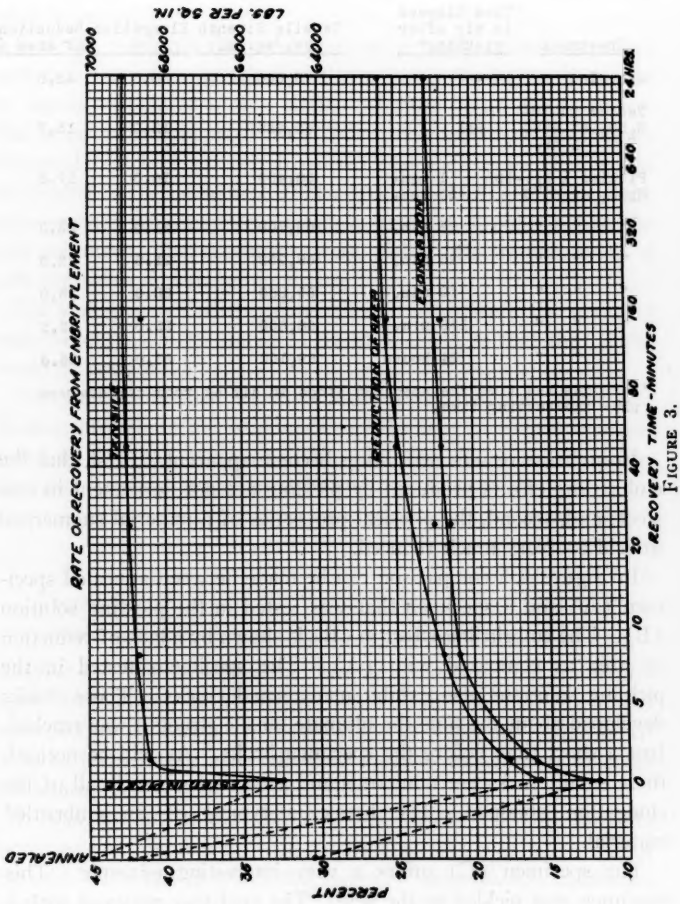

LBS. PER SQ. IN.
70000
66000
66000
64000
24 HRS.
640
380
160
80
40
20
10
5
0
RECOVERY TIME - MINUTES
RATE OF RECOVERY FROM EMBRITTLEMENT
TENSILE
REDUCTION OF AREA
ELONGATION
ANNEALED
45
40
35
30
25
20
15
10
PERCENT

FIGURE 3.

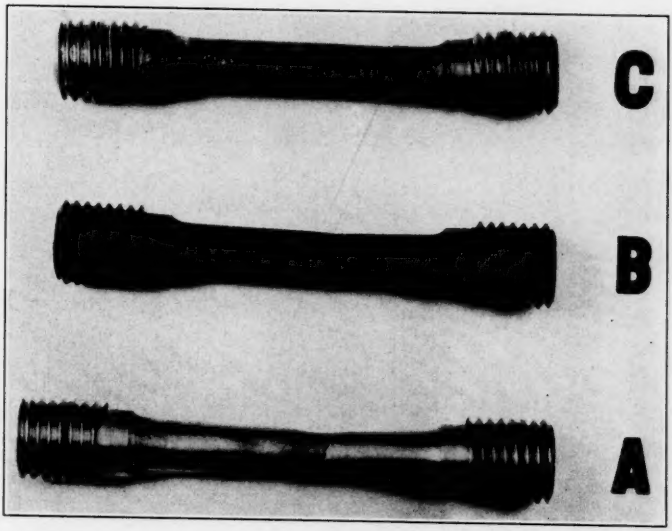


FIGURE 4

ject to the attack of the very dilute acid, which points out that this very slight pickling effect was sufficient to select the location of the break. The hydrogen penetration through this area had not stopped and consequently the physical properties were at a minimum, whereas the remainder of the specimen was on its way to recovery from embrittlement.

Chemical vs. Electrolytic Pickling—Since other investigators have studied at great length the effects of electrolytic pickling, it was thought advisable to compare this method with the chemical pickling methods. In Table VI the results of this study are compared. The chemical pickling is the more drastic although there is very little difference between it and the cathodic pickling. The effect of anodic pickling is not as pronounced, though the specimens were very badly pitted. This, however, might have been prevented somewhat if an inhibitor had been added.

Table VI

Comparison of Electrolytic and Chemical Pickling

Treatment	% H_2SO_4	Tensile Strength lbs./sq.in.	Elongation %	Reduction of area %
Pickled 1 hr. as cathode	10	66,400	14.5	16.0
Pickled 1 hr. as anode	10	66,600	19.0	25.0
Pickled 1 hr. chemically at 65°C	10	65,625	12.0	15.7

Specimens tested in acid.

The Effect of Inhibitors—Considerable has been said about the action of inhibitors and the results of other investigators have been presented. Therefore, it was not considered advantageous to go into lengthy testing with various inhibitors. The important feature brought out in the study of inhibitors (Table VII) is that they are responsible for a decrease in the degree of embrittlement. This decrease in the amount of embrittlement is very small. The reason the inhibitor is beneficial in preventing the embrittlement from attaining its full value probably lies in the fact that it reduces the acid attack on the steel and consequently there is not as much hydrogen formed to penetrate the specimen. It does not prevent embrittlement as certain commercial concerns have suggested.

Table VII

Effect of Inhibitors in Embrittlement due to Pickling.

Inhibitor	Tensile Strength lbs./sq.in.	Elongation %	Reduction of Area %
None	65,625	12.0	15.7
Quinoline Ethiodide 0.01%	66,850	16.0	19.0
Commercial inhibitor	66,100	16.5	19.5

All samples pickled 1 hour at 65° C in 10% H_2SO_4 and tested in acid.

The Effect of Pickling on the Internal Friction of Steel—The results and conclusions of other investigators have pointed out that all acids commonly used in pickling cause a weakening at the grain boundaries of pickled steel. Since this is the case, pickling should have an effect on the internal friction of steel as measured on the apparatus designed and reported on by Dr. R. H. Canfield (44), (45), (46), of the Naval Research Laboratory. Therefore, a cold rolled steel specimen of a medium carbon content was selected and tested while pickling. This specimen had previously been twisted through an angle of 180 degrees but, as considerable time had elapsed since it was twisted, the aging effect was considered to be negligible.

In order to carry out the pickling operation, the bottom of the hollow specimen was closed by a rubber stopper. A platinum wire, to be used as the anode, was run through the center of the specimen. After a set of readings had been taken to obtain the curve of the unpickled specimen, 10 per cent sulphuric acid was placed in the center of the specimen. It was then pickled electrolytically as the cathode with a current density of 0.4 amperes per square inch. Readings were taken periodically during the pickling operation.

The specimen was pickled for two hours and then the acid was removed and the specimen washed with distilled water to remove all traces of acid. Readings were taken at intervals to determine the rate of recovery after pickling.

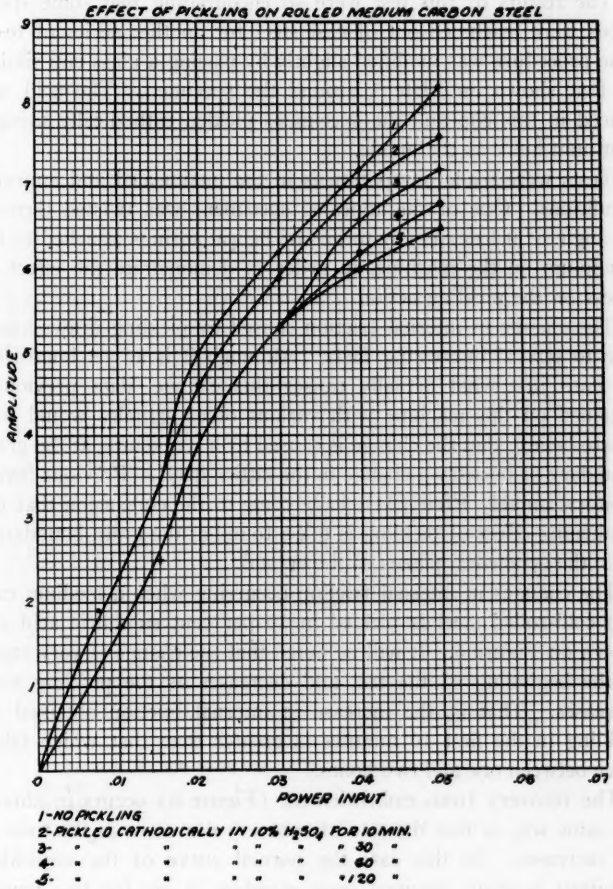

EFFECT OF PICKLING ON ROLLED MEDIUM CARBON STEEL
AMPLITUDE
POWER INPUT
0
.01
.02
.03
.04
.05
.06
.07
1
2
3
4
5
6
7
8
9
1-NO PICKLING
2-PICKLED CATHODICALLY IN 10% H2SO4 FOR 10 MIN.
3- " " " " " " 30 "
4- " " " " " " 60 "
5- " " " " " " 120 "

FIGURE 5.

The method of testing was the usual procedure for this machine except for the pickling operation and the fact that the machine was kept running at a low amplitude (2 cm) between readings.

The results of this test were so encouraging that some specimens were machined out of cast steel for another series of tests. The procedure was modified slightly by placing a glass cup similar to that shown on Plate 1 around the specimen. The acid was placed in this cup and the specimens pickled cathodically using a platinum helix as the anode.

Tests were made on specimens in the unannealed and annealed conditions. One of the annealed specimens was twisted through an angle of 0.4 degree, by means of helical springs attached to the pendulum on the machine, in order to demonstrate the effect of stress on the pickling action.

The change in internal friction caused by pickling draws attention to several interesting facts. Although it is as yet impossible to state just what actually causes this change, data previously obtained on this machine with various other samples would lead one to believe that the change is caused by a weakening at the grain boundary or possibly a change in the lattice itself. Previous investigators, notably Pfeil (24), have come to the conclusion that the weakening effect of pickling is to be found at the grain boundaries or in the octahedral planes of the crystal.

The changes in internal friction occurring when a medium carbon cold-rolled steel is pickled in 10 per cent sulphuric acid are shown on Figure 5. It will be noted that the change is very rapid at the beginning of the test and decreases as the pickling time increases. That is, the increase in internal friction obtained by pickling in the first 10 minutes is greater than that which takes place between one and two hours.

The recovery from embrittlement (Figure 6) occurs in almost the same way in that the rate of recovery decreases as the time in air increases. In this case the normal curve of the unpickled specimen is again obtained upon standing in air for two hours.

The "as cast" steel specimen (Figure 7) shows an increase in internal friction upon pickling similar to the cold-rolled specimen, although the effect is not so great. This is probably due to

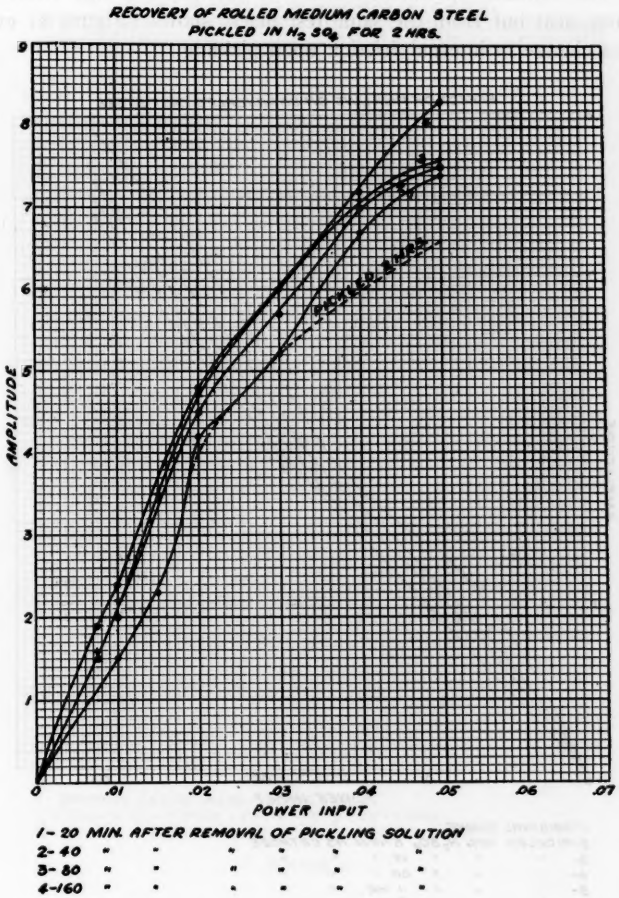


FIGURE 6.

the fact that the cold-rolled specimen had previously been twisted through an angle of 180 degrees and, therefore, was in a more stressed condition.

The annealed specimen, which was obtained not only from the same heat but from the same test block, shows (Figure 8) even less change in internal friction upon pickling.

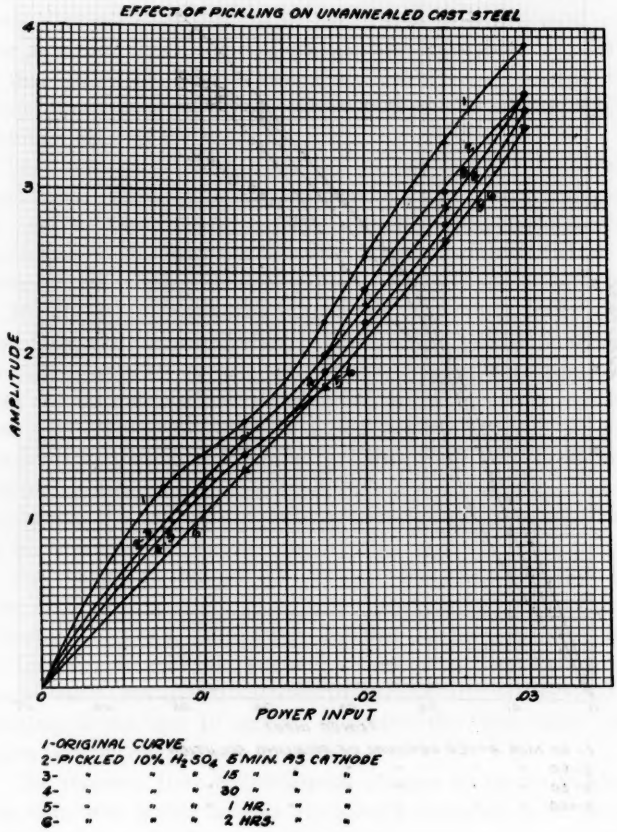


FIGURE 7.

These results agree very well with those obtained by previous workers and in the tensile tests mentioned above. That is, the degree of hydrogen embrittlement appears to be a function of the amount of stress present in the pickled object. This appears to

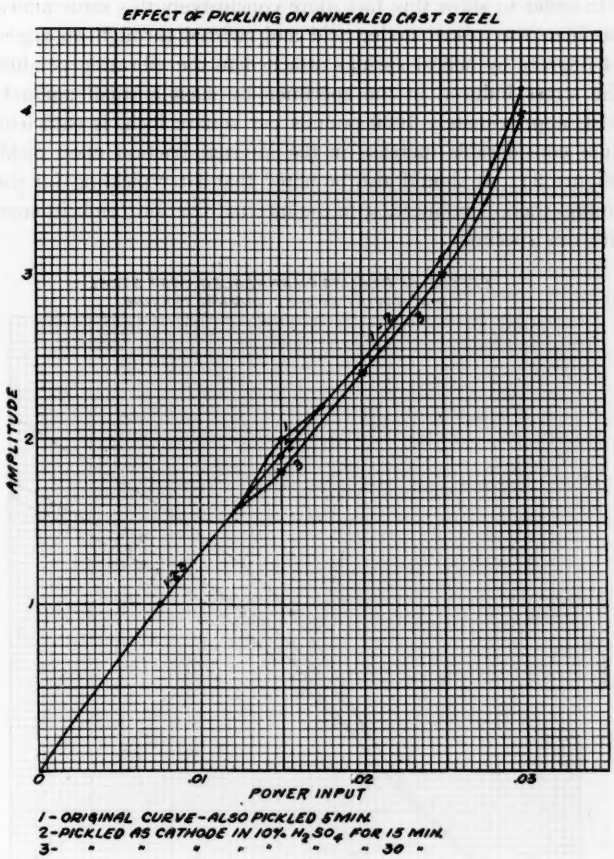


FIGURE 8.

be quite reasonable as it is logical to assume that the amount of embrittlement is proportional to the amount of hydrogen present and Williams and Homerberg (22) have shown that the amount of hydrogen penetrating a specimen increases as the load increases up to the yield point. Above the yield point an increase in the load does not increase the amount of hydrogen penetration.

In order to show this fact more conclusively this same annealed specimen was tested under acid and twisted through an angle of 0.4 degrees by helical springs attached to the vibrating pendulum. The stress induced in the specimen by such a small amount of twist, approximately 7000 pounds per square inch, is sufficient to cause considerable increase in the internal friction upon pickling (Figure 9). It should also be noted that after pickling for thirty minutes there is no increase in the internal friction (embrittlement) with this specimen.

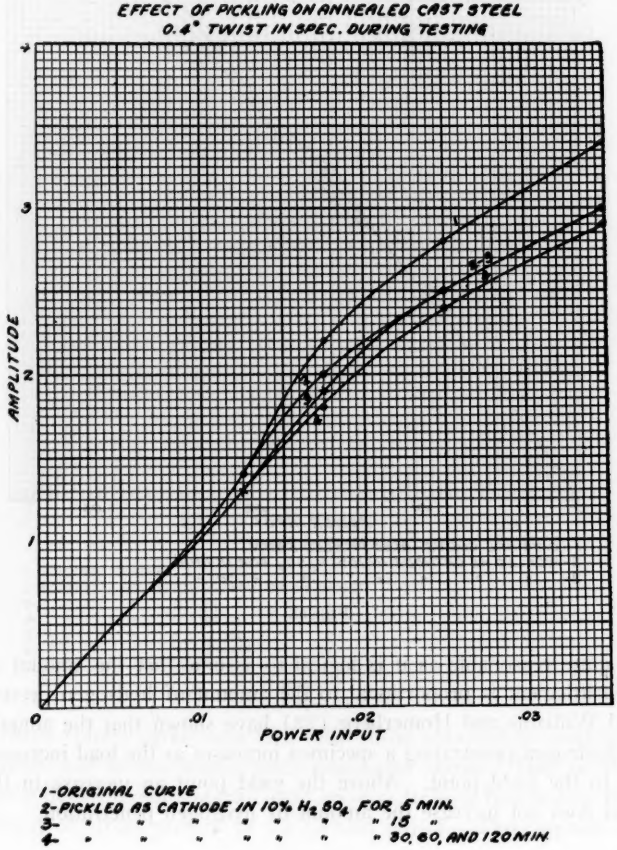


FIGURE 9.

The recovery from pickling embrittleness was also studied with this specimen (Figure 10). It will be noted that although the sample does recover to some extent, the recovery is not complete even after standing eight days in air.

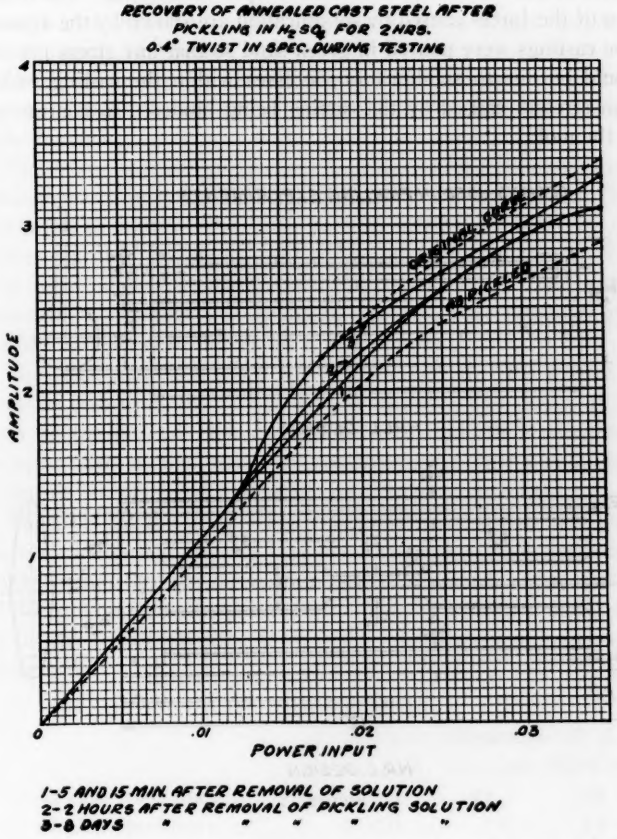


FIGURE 10.

Effect of Pickling on Experimental Castings—It was thought advisable to conduct some experiments on castings to show the effect of pickling on different shapes. Two small castings some-

what similar in design were chosen for this purpose. One, the Hall pattern, shown on Figure 11, is designed in such a manner that the small member used in testing is in compression upon solidifying. In the Naval Research Laboratory design, the center member, used in testing, is in tension upon solidifying. The direction of the forces caused by solidification are shown by the arrows. The castings were poured in green sand so that any stress present would be due to solidification, stresses within the casting rather than stresses caused by the casting being hindered in contracting by the mold.

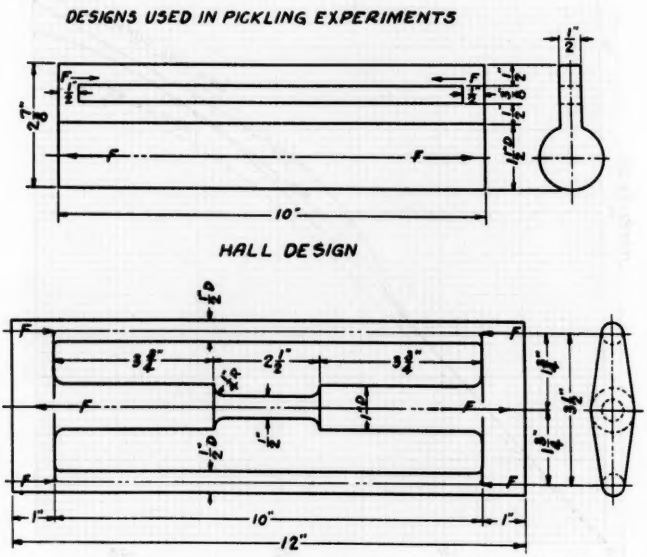


FIGURE 11.

Both types of castings were pickled in a bath of 10 per cent sulphuric acid, maintained at a temperature of 65 degrees C. (150 degrees F.) for 45 minutes. After pickling, the castings were washed in cold water and then, as the stresses were not sufficient to crack the castings, the small member of the Hall pattern and

the center member of the Naval Research Laboratory design were cut off and tested in a tensile machine. The test pieces were cut off as rapidly as possible and tested immediately in order to prevent as much recovery of embrittlement as possible. Cold water, rather than hot water, was used as a wash for the same reason. The average time required to wash, cut off, and test a specimen was approximately 12 minutes.

The small member of one of the Hall castings was cut in two and the amount of contraction measured. This amounted to 0.021 inch.

The center member of one of the Naval Research Laboratory castings was also cut and the resulting expansion measured. This amounted to 0.023 inch. The casting was then placed in the testing machine and compressed to the original dimensions. The load required was 11,360 pounds per square inch. The actual stress in the casting was probably of this order although this method of obtaining the stress is not accurate.

The small pickled castings showed definitely that the important stress in embrittlement by hydrogen is tension. The results of the tests on the pickled Hall castings showed that the pickling had no great effect on the member in compression as there was no drop in tensile strength and practically no change in ductility.

The tests on the Naval Research Laboratory design using the member in tension showed that this stress was very important. Even though the specimens were pulled in air after the interval of 10 to 12 minutes required to saw off the specimen and set it up in the tensile machine there was a decided drop in physical properties.

	Tensile Strength		
	Pounds per Square Inch	*Elongation Per Cent*	*R. A. Per Cent*
"As cast" specimen	67,700	17	23
Pickled specimen	60,950	7.5	13

DISCUSSION.

It has been shown from the preceding data that pickling is responsible for an embrittling effect. This brittleness is brought about by an absorption of atomic hydrogen by the steel.

A careful search of the literature indicates that there is no conclusive evidence available regarding the manner in which the atoms of absorbed hydrogen are distributed through the mass of solid iron. There appears to be considerable conflicting evidence as to the existence of metallic hydrides. However, it has been shown by several observers (43) that an increase in volume and a change in electrical conductivity occur in most metals when absorption takes place. With copper, palladium, and platinum, a positive expansion of the space lattice has been measured. It is also known that absorptive forces can cause spontaneous pulverization especially in the softer metals. It is likewise apparent that the absorbed hydrogen can eventually collect in the form of local concentration areas, which have the power of disrupting the space lattices to form a discontinuity.

Slater (42) believes that the absorption evidence suggests that the hydrogen atom is initially held interstitially in the space lattice and that absorption of further quantities of hydrogen may result in the attainment of a second stage in which hydrogen agglomerates at local areas such as grain boundaries and non-metallic inclusions. Then if a relatively slowly applied stress, such as that occurring in the tensile, bend, or torsional tests, is applied, it will result in the breakdown of the initial interstitial solid solution, with subsequent agglomeration of hydrogen to produce a series of local stress concentrations or even disruptions.

There appears to be no record of castings failing to destruction as a result of pickling. What is usually encountered is a series of surface cracks which may or may not penetrate to a considerable depth. These cracks are unquestionably caused by pickling. The actual process of formation of the cracks is not known definitely, but Slater's hypothesis seems to explain them better than any other for:

1. It is difficult to understand how the slight loss in tensile strength and the low ductility obtained as a result of pickling could cause cracking unless a bending movement were also present.

2. As the yield point of steel immersed in acid is apparently higher than that obtained in air, it does not seem tenable that the stresses present in the casting would be great enough to cause the metal to yield enough to cause cracking even though the ductility is low.

Since cracks resulting from pickling are found mainly on the surface of a casting, the surface imperfections which are present in all castings may be sufficient to cause stress concentration and crack development. Once a beginning is made, the progress of the crack is merely the result of the centralization of stresses at the point of the crack. When the stresses have been relieved the cracking stops.

The work of previous investigators and the data obtained at the Naval Research Laboratory bring out the fact that internal stress is one of the most important contributors to embrittlement in steel. If it were possible to obtain a piece of steel in the unstressed condition, it is highly probable that it would exhibit no embrittlement upon pickling. All of the data collected points to the fact that the greater the internal stress the greater the degree of embrittlement will be. This is probably shown best by the data obtained on the Canfield internal friction machine. The annealed specimen was embrittled less than the "as cast" specimen. A slight twist of the annealed specimen increased the brittleness markedly.

It should be noted that even though the annealed specimen had received a full anneal, embrittlement was still to be found. This points out the fact that castings that require pickling must receive a full anneal prior to this operation. As many so-called "commercial anneals" are not full anneals and are in fact, in many cases, merely a normalizing treatment, there is real danger of cracked castings resulting from pickling.

The embrittling effect due to pickling is mainly a temporary effect. The steel will usually recover and have almost its original physical properties if allowed to stand in air about three days or is boiled in water for an hour. It will never recover all of its physical properties, however. The portions that are permanently lost are probably due to a roughening of the surface which causes a concentration of stresses at the minute holes and cracks etched out. Therefore, any casting which has not been cracked during the pickling operation has probably not suffered a great deal as far as physical properties are concerned.

Due to this rather rapid recovery from embrittlement, tensile tests of portions of cracked castings will give no indication of

hydrogen embrittlement. Tensile tests will not show the true embrittling effect unless the specimen is submerged in acid during the tests. The time lost in cutting out a portion of the casting and machining it to size and the heat generated during cutting and machining are usually sufficient to remove any occluded hydrogen and embrittlement.

ACKNOWLEDGMENT.

The authors wish to acknowledge the cooperation of Dr. R. H. Canfield in obtaining data on the internal friction of pickled cast steel and also the assistance of Mr. James Darby in carrying on the remainder of the tests.

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A CRITERION FOR SCOOP CAVITATION.

By HENRY F. SCHMIDT.

Any rational design of scoop should be such as to produce the lightest and most compact piping arrangement. The scoop should also be made as short as possible to avoid cutting any more frames than necessary. This involves making the scoop with as short a radius as permissible without interfering with its performance or producing cavitation, which would reduce the capacity and pressure available for overcoming condenser resistance.

When a fluid passes through an elbow or turn, owing to the reduction of pressure at the inner radius, the velocity at the inner radius increases and decreases at the outer radius. This is necessary in order to fulfill the law of conservation of energy, which states that the total head must remain constant.

The water in the frictional wake belt adjacent to the hull varies with the distance from the skin, the velocity at the surface being approximately 50 per cent of the ship's velocity and increasing rapidly as the distance from the hull increases. Within the range of interest in the design of scoops, *viz.*, 14 to 15 inches, the relative velocity of the water with respect to the hull varies from approximately 50 per cent to 90 per cent of the ship's velocity. The integral of the kinetic energy of the water within this range varies from about 60 per cent to 65 per cent of the velocity head, corresponding to the ship's velocity through still water.

In order to find the minimum radius of the scoop which may be employed without cavitation, it is necessary to find the force or pressure required to deflect the water into the scoop entrance.

Figure 1 shows a scoop of the lipless type with an inner radius, R_2, and an equivalent protrusion equal to $R_1 - R_2$. That is, all the water within the radius R_1 enters the scoop.

As has been pointed out, the effect of making a turn is to increase the velocity of the water at the inner radius and decrease

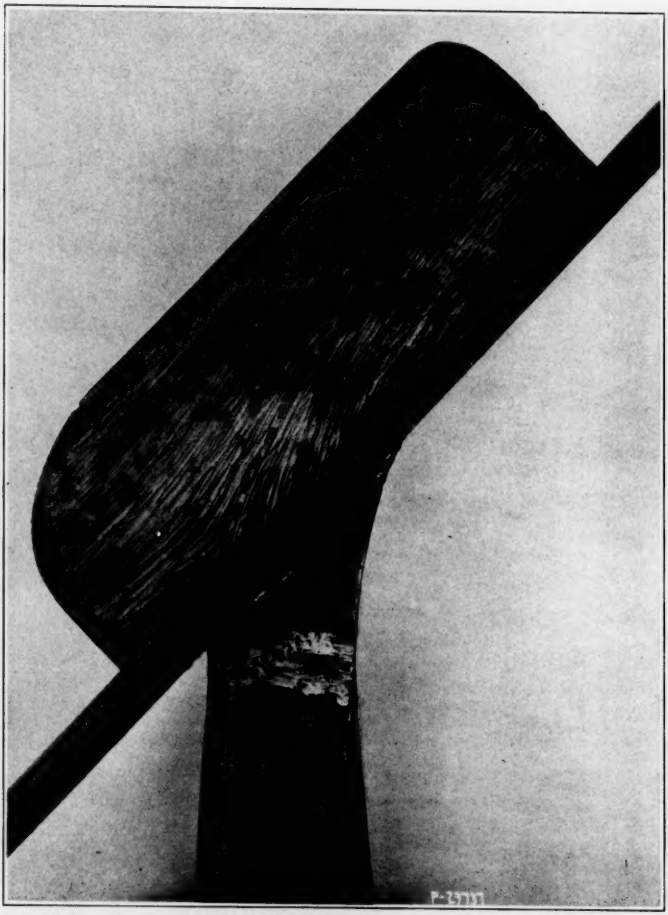

FIGURE 2.

the velocity of water at the outer radius, and the velocity of the water in the frictional wake belt is greatest at the skin and highest in the outer layers. Consequently, we will not make any considerable error in assuming that these two effects neutralize each other and that, for calculation purposes, we can take the velocity over the whole equivalent protrusion as being constant and corresponding to the mean integrated velocity head.

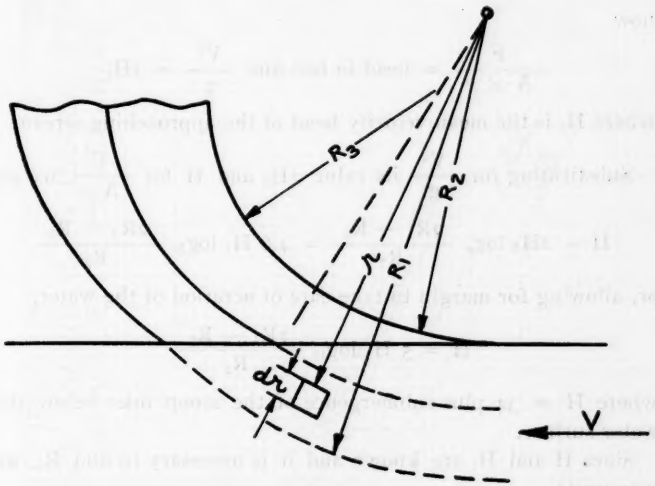

FIGURE 1.

Now, from an examination of Figure 2, it is seen that the water farther out beyond the layer entering the scoop is also deflected, and that beyond about twice the thickness of the entering layer, there is no appreciable effect, owing to the fact that the water also fills in from the sides to some extent, as well as from farther out. As a result of this, the centrifugal force tending to reduce the pressure at the inner radius is due to a stream of nearly twice that entering the scoop, so we must take the integral between $2R_1 - R_2$ and R_2. $(R_1 + R_1 - R_2) = 2R_1 - R_2$.

If we assume a small element in the stream of area A and thickness dr at radius r, the centrifugal force on this element will be

$$dF = \rho\, A\, dr\, \frac{V^2}{gr} \quad \text{where } \rho \text{ is weight per cubic foot.}$$

from which

$$F = \int_{R_2}^{2R_1 - R_2} \rho\, A\, \frac{V^2}{g}\, \frac{dr}{r} = \rho\, A\, \frac{V^2}{g} \log_e \frac{2R_1 - R_2}{R_2}$$

now

$$\frac{F}{A \times \rho} = \text{head in feet and } \frac{V^2}{g} = 2H_1$$

where H_1 is the mean velocity head of the approaching stream.

Substituting for $\frac{V^2}{g}$ its value $2H_1$ and H for $\frac{F}{A\,\rho}$ we get

$$H = 2H_1 \log_e \frac{2R_1 - R_2}{R_2} = 4.6\, H_1 \log_{10} \frac{2R_1 - R_2}{R_2}$$

or, allowing for margin to take care of aeration of the water,

$$H = 5\, H_1 \log_{10} \frac{2R_1 - R_2}{R_2}$$

where H = 34 plus submergence of the scoop inlet below the water surface.

Since H and H_1 are known and it is necessary to find R_2, we may write

$$\frac{H}{5H_1} = \log_{10} X \qquad \text{where } X = \frac{2R_1 - R_2}{R_2}$$

or, if the equivalent protrusion in inches is denoted by P, and since $R_1 = R_2 + P$

$$R_2 = \frac{2P}{X - 1} \text{ inches.}$$

The value of R_2 may be plotted for different speeds as in Figure 3.

From this equation, it will be seen that cavitation depends only on the ratio of the radii and the velocity of the water and the total head available to counterbalance the centrifugal force of the

water in making the turn. This has been verified by shop experiments with water, using an inner radius as small as 4 inches and a water velocity corresponding to 30 knots.

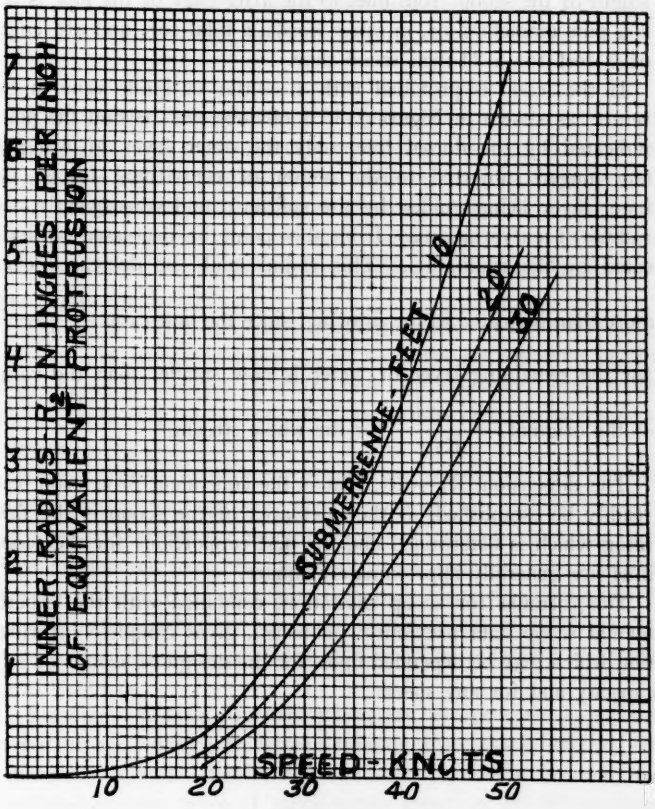

FIGURE 3.

Because of the previously stated assumptions from which it results, the logarithmic form of the equation must be considered only as a practical approximation sufficiently close for design purposes, and not as a mathematical truth.

The complete problem is of such extreme complexity that an exact mathematical solution is an impossibility.

A scoop of the proportions shown in Figure 1 can be employed without cavitation at speeds up to 34½ knots with a submergence of 10 feet, and it will be observed that the total fore and aft length of the scoop from inlet to the after edge of the pipe is but 2½ pipe diameters, or, in other words, a total fore and aft length of 5 feet for a 24-inch scoop pipe.

If the scoop is provided with a splitter or guide vane in the center, as shown in Figure 1, it is obvious that beyond the point indicated by the dotted line, only the outer layer of water is any longer subjected to the action of centrifugal force (the inner layer being guided by the splitter), and consequently, the radius of curvature may from this point be decreased as indicated by the radius R_3. This radius could be decreased even more than indicated in the drawing, since the new ratio $\frac{2R_1 - R_2}{R_2}$ for the remaining layer of water is now smaller than the value of the original $\frac{2R_1 - R_2}{R_2}$ for the whole stream.

The dimension, $R_1 - R_2$, that is the equivalent protrusion, can readily be established, as the inlet area of the scoop is the first thing which is determined and the best proportions for the scoop inlet are generally approximately square.

The formula for scoop cavitation, combined with the experimental scoop data previously published, gives complete information which may be depended upon for the design of scoops of any capacity and for any speed.

STEEL FORGINGS.

By P. E. McKinney.*

While the art of forging is probably the oldest known method of putting metal into usable form, present-day forging practice is by no means a relic of primeval metal working art. In those ancient days, forging was resorted to as the only available method for roughly shaping the mass of metal, while today it constitutes a very important link in the chain of refinements given the piece to put it into usable form.

The prime object of modern forging practice is to mechanically deform and work the metal so as to break up ingotism or the coarse grain of the cast structure, and to produce flow lines in the piece which will most favorably resist the stresses imposed in service.

In the process of evolution which has resulted in our modern fighting ships, forgings have played no small part. With the ever increasing demands for more efficient performance forgings have been chosen and found to answer the need when the most exacting service is imposed on materials. Generally speaking, other methods of fabricating metals are compared with forgings on the basis that forgings rank highest from the standpoint of reliability in service performance.

Forgings, in their broadest sense, are the product of various types of hot working equipment ranging from small hand or mechanically operated hammers to monster hydraulic presses, and includes various types of quick-acting steam or air driven hammers, motor driven hammers, upsetting machines and draw benches. In this discussion we will confine ourselves largely to heavy and medium size forgings of the types used in naval engineering, power plants and similar activities.

The methods to be used in production of a forging will vary depending on the design and the nature of service for which it is

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intended. No fixed rule can be set down regarding the relative merits of presses, hammers or other types of equipment for general work, other than the requirement that the equipment used must be adequate for giving the material a proper amount of directional work throughout its mass. As an instance, a heavy forging might be brought to final shape by the use of a rather small hammer or press but on account of the heavy cross-section the energy of the blows or pressure would be dissipated in the outside layers of the piece and the center would receive no appreciable mechanical working, whereas on a forging of somewhat smaller cross-section the same equipment would be entirely adequate. The importance of having forging equipment of ample capacity to thoroughly work the mass cannot be over-emphasized. The selection of forging capacity for a given job is too frequently viewed from an economic standpoint whereas it is plainly evident that adequacy of the equipment to thoroughly work the metal is a far more important consideration.

The selection of metal of the proper quality and grade for a given type is a very important consideration in the production of good forgings and involves many other features than chemical composition and the melting process employed in its production. The general term " forging quality " is a very broad one and does not signify a single grade of steel suitable for the production of all classes of forgings.

All forging steel must necessarily be fully malleable over a wide range of temperatures, but in many other respects its required characteristics will differ depending on the type of forging and subsequent treatment operations contemplated as well as the desired characteristics of the finished forging.

Raw material used for forgings is in the form of ingots, blooms, or billets. Ingots are used either as received hot from the melting plant or cold. It is generally conceded that for the best forging practice, ingots received hot after stripping from the molds and properly equalized and reheated to forging temperature is the ideal form of raw material. Blooms and billets of proper quality are next in order of preference. For many types of small forgings it is obviously impractical to use any other form than blooms or billets. Generally speaking, cold ingots are the least desirable

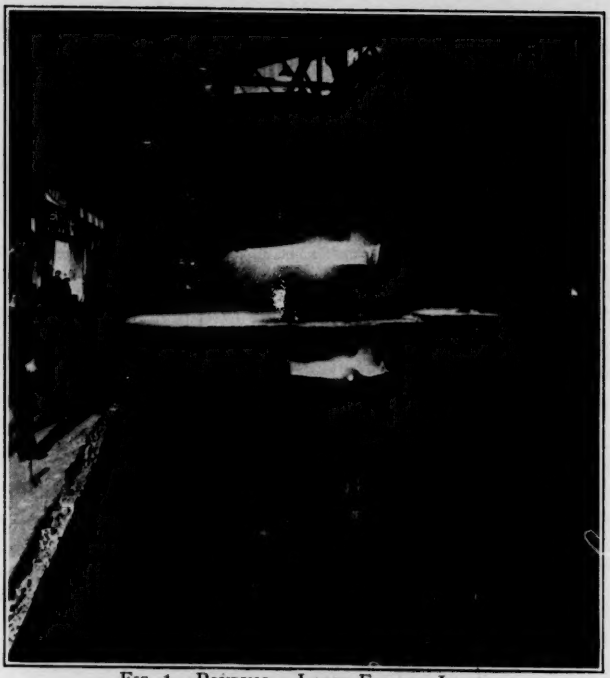


FIG. 1.—POURING A LARGE FORGING INGOT.

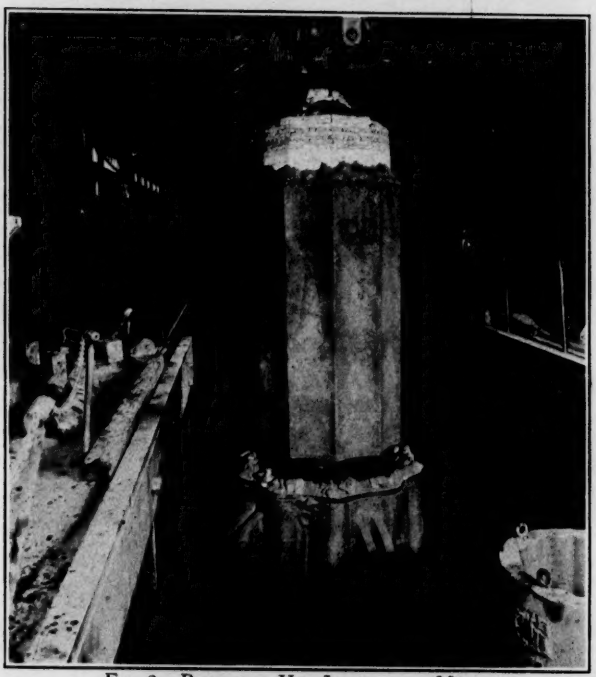


FIG. 2.—REMOVING HOT INGOT FROM MOLD.

form of raw material for forging and unless they have been carefully annealed or otherwise treated previous to reheating for forging may introduce serious hazards and detract from the quality of the finished product.

A great deal could be written regarding melting operations for forging steel, the details of which must necessarily vary depending on the type of forging contemplated. Regardless of the steel-making process used the operation of melting, refining and finishing, the melt must be carefully controlled. In the best practice, composition of slag as well as metal is carefully regulated throughout the entire operation. In the production of steel for the heaviest forgings, special precautionary measures are necessary on account of the prolonged time cycle involved in the solidification of the ingot.

The selection of proper types of ingot mold equipment is of equal importance to melting and forging operations. A well-organized forging plant should have available a number of types and sizes of ingots from which to select the one most suitable for producing a given forging with particular reference to obtaining the proper amount of directional work and discard. In the production of quality forgings from blooms or billet stock, the forger should know the size and type of ingot used so as to regulate the amount and character of forging work to obtain the proper directional properties in the product.

Good forging ingots are invariably cast in metal molds. The most desirable type is of round design with a proper number of heavy longitudinal corrugations, and increasing in cross-section from the bottom to the top. The top of the ingot is provided with a hot top, which is a flask lined with refractory material, and which acts as a reservoir from which molten metal is fed into the ingot during solidification, and permits the natural segregation incidental to solidification to that portion of the ingot that is discarded. Sizes of forging ingots vary from about 16 inches to 108 inches nominal diameter and in weight from about 4000 to 450,000 pounds.

The design of ingot molds involving the relation of the various dimensions, shape of corrugations, etc., is a very important feature. The development of ingot mold design is not based on theory alone

but has been confirmed by considerable research involving the actual sectioning of typical ingots of selected sizes that will fairly represent the characteristics of the various size ingots of a given design. These sectioned ingots have been studied by making a complete sulphur print of the entire cross-section, taking drillings for study of segregation, and by examination for non-metallic inclusions. This method of research, while quite costly, furnishes permanent data as to the normal degree of segregation, permits the intelligent planning of forging operations and definitely determines the proper discard to be taken from the ingot.

A great deal of attention is given to temperature and pouring speed in teeming forging ingots. For each size and type of ingot a bogey limit for pouring conditions is established, largely based on experience for both carbon and alloy steel. Due to the fact that by adjustment of these factors the characteristics of the ingot may be controlled, every effort is made to stay within these established limits.

Forging operations involving longitudinal forging under flat or "V" dies, upsetting, punching, hollow forging over mandrels either for enlargement or elongation of the forging are resorted to with consideration of the purposes for which the forging is to be used and the customer's requirements for physical characteristics. Since the prime object of forging is to work the metal in the direction that will increase its resistance to the maximum service stresses, it is important before planning a forging operation on a given piece to have a rather thorough knowledge of the character of service contemplated and an approximation of the magnitude and direction of the service stresses which will be imposed.

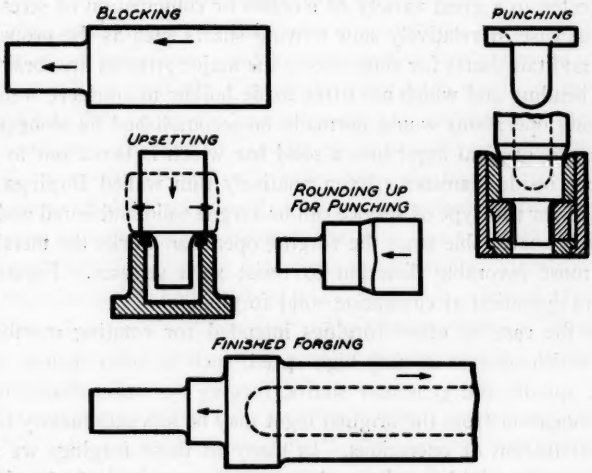
Specifications frequently attempt to cover in detail required methods of forging, supplemented by definite physical requirements, for test bars taken from different planes as related to the major axis of the piece. Unless such specifications cover a single type of forging such, for instance, as the present Navy requirements for boiler drums, they are bound to fall short of their object and will often result in the furnishing of far less satisfactory product than is the case when forging work can be planned, based on a knowledge of the service requirements.

Probably the best example of adapting forging procedure to the requirements of service is in the case of hollow cylindrical forgings. In their various service applications hollow forgings are subjected to a great variety of stresses or combination of stresses. In the case of relatively slow moving shafts such as the propeller line and tail shafts for ships where the major stresses are torsional and bending and which are often made hollow to conserve weight, forging operations would normally be accomplished by elongating from the original ingot into a solid bar which is bored out to the proper inside diameter. Even relatively thin walled forgings intended for this type of service can be forged solid and bored and be entirely serviceable since the forging operation works the metal in the most favorable direction to resist such stresses. Figure 3 shows operation of elongating solid forging.

In the case of other forgings intended for rotating members, but which operate at very high speed, such as rotor drums, turbine, spindle and generator shafts, forging operations based only on elongation from the original ingot may be less satisfactory than a combination of operations. In many of these forgings we are confronted with high radial and tangential stress in the body of the forging and torsional and bending stresses on the journal ends. Forging operations on a piece of this character involve upsetting of the body so as to favor radial stresses, in many cases partial punching, hollow forging of the body as in the case of large rotor drums and elongation of the journal end to favor torsional stresses. Figure 4 shows the evolution of forging operations on a forging of a type similar to rotor drums.

In the case of cylindrical forgings intended to resist internal pressure such as boiler drums and oil refinery vessels, hollow forging is recognized as the best and safest method of manufacture. In any case where the metal in the wall of such a forging is subjected to an appreciable stress the boring of a solid forging cannot be classed as an entirely safe procedure. In the production of such forgings the original ingot is preliminarily forged by rounding, and after the removal of discard metal, is upset to a sufficient degree to thoroughly work the whole mass in a direction at right angle to the exis. The center of the block is then removed by punching or hot trepanning. The hollow block is then forged on

FIGURE 4
ROTOR DRUM
FORGING OPERATIONS



a mandrel and after expanding to approximately the desired diameter it is elongated by further forging on suitable size mandrel to the desired length. In cases where ends must be closed or necked in to provide end closure, forging operations are carried out to provide heavier metal on the end of the cylinder. The rough forged cylinder is then machined to bring the bore to size and to shape the ends so as to permit symmetrical formation in the necking operation. The ends of the drum are then heated and closed in with special dies. Figures 5 to 10, inclusive, show operation involved in the production of hollow forgings. Figure 11 shows a diagram of shape and directional work involved in forging of a boiler drum.

A very interesting and efficient method for producing hollow forged cylinders which is applicable when a number of cylinders of one size are required is by upsetting, punching and drawing. In this process the hot ingot, after rounding up and removal of discard is upset, then placed in a large container and further upset followed by punching to form a heavy-walled cup-shaped blank.

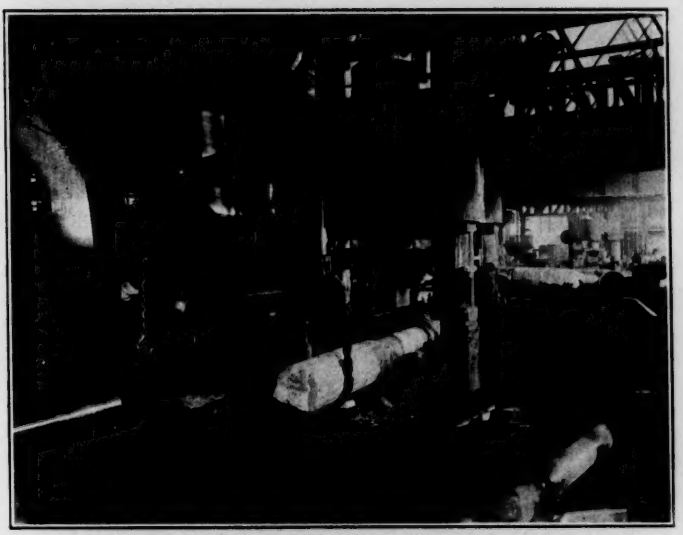


FIG. 3.—PRODUCTION OF SOLID FORGING BY ELONGATION.

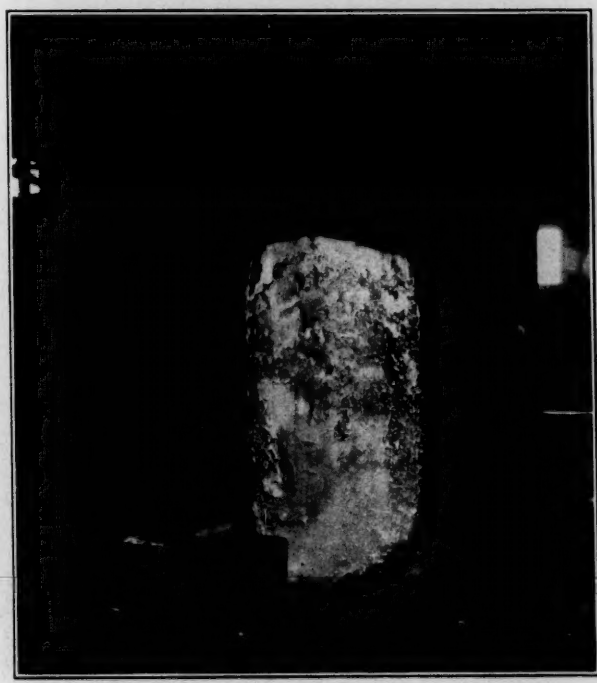


FIG. 5.—UPSETTING INGOT BODY AFTER ROUNDING AND REMOVAL OF DISCARD.

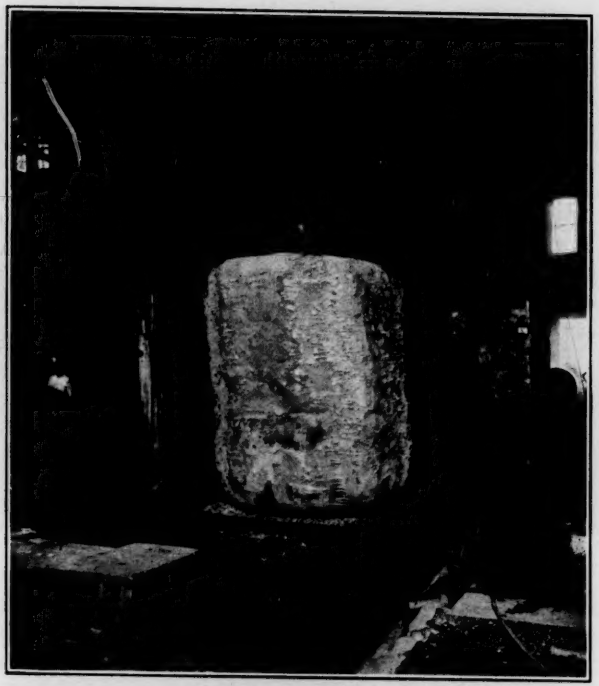


FIG. 6.—PUNCHING UPSET BLOCK.

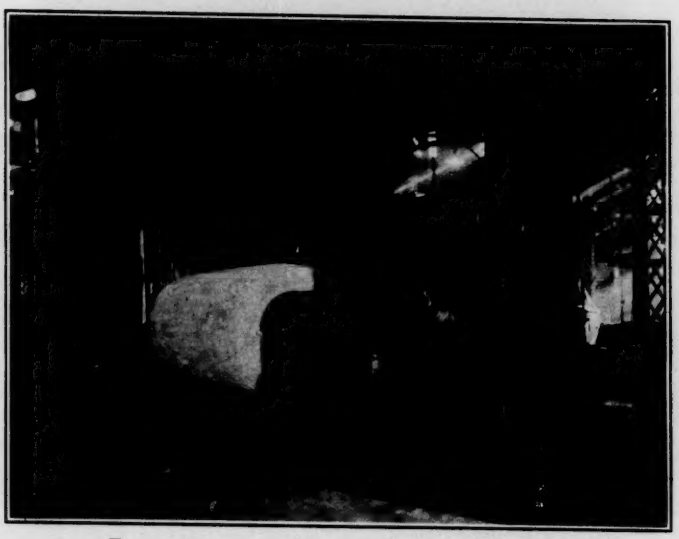


FIG. 7.—ENLARGING PUNCHED BLOCK ON MANDREL.

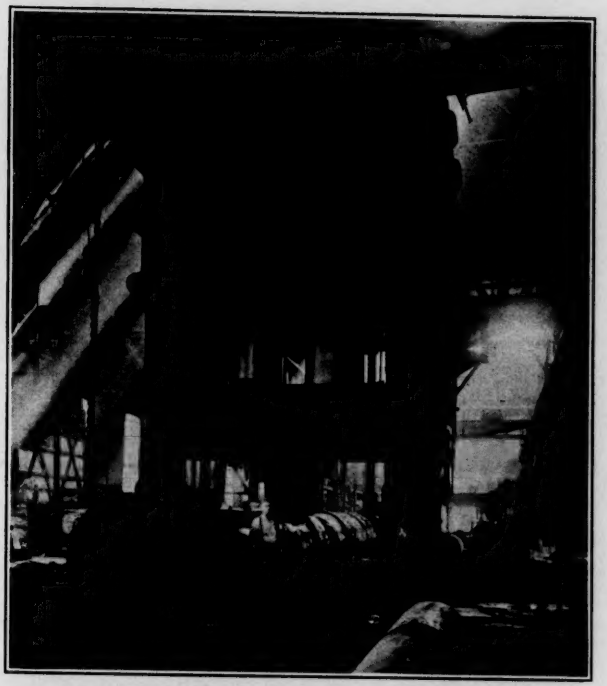


FIG. 8.—ELONGATING HOLLOW FORGING.

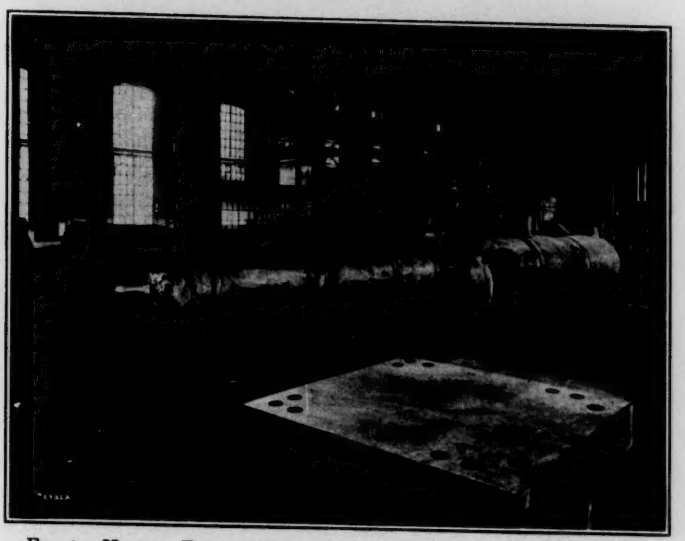


FIG. 9.—HOLLOW FORGING READY FOR CLOSING OR NECKING OPERATION.

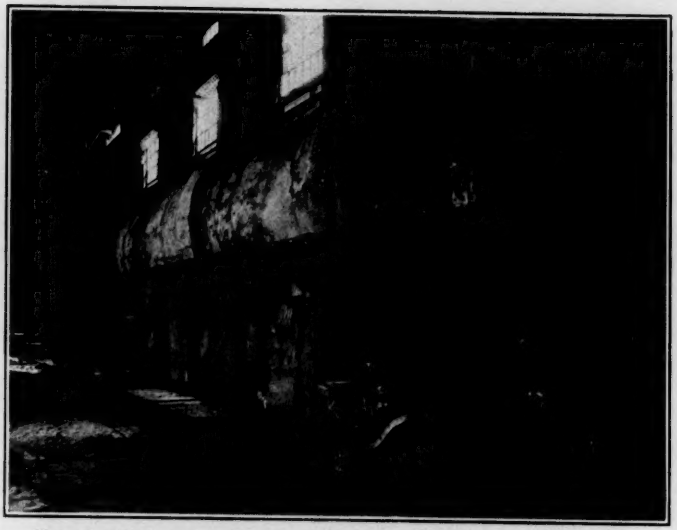


FIG. 10.—ROUGH FORGING WITH CLOSED ENDS READY FOR MACHINING.

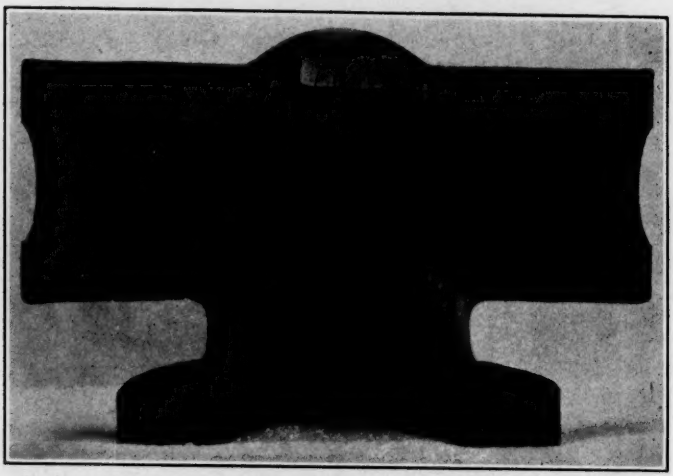


FIG. 13.—SECTION OF FINISHED VALVE FORGING WITH UNSATISFACTORY FLOW LINES.

FIGURE 11

WATER DRUMS & STEAM DRUMS FORGING OPERATIONS

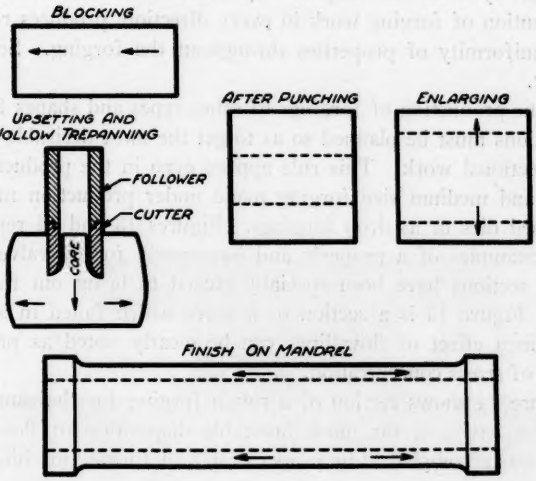
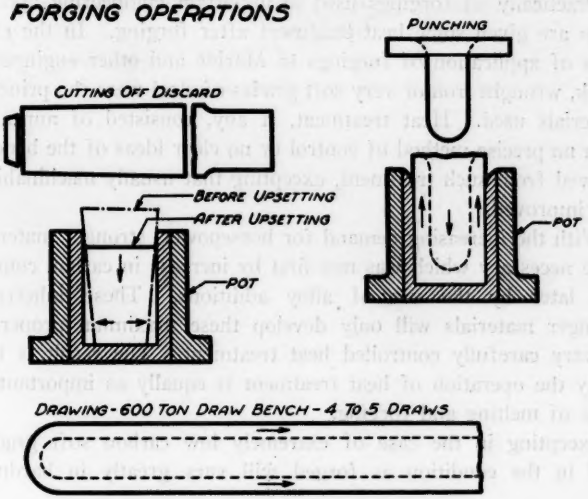


FIGURE 12

AIR FLASK FORGING OPERATIONS



This cup-shaped blank is then drawn into a cylinder by passing through a succession of dies in a heavy draw bench which reduce the wall by successive steps. This process, due to the favorable distribution of forging work in every direction, produces remarkable uniformity of properties throughout the forging. See Figure 12.

In the production of forgings of other types and shapes forging operations must be planned so as to get the most desirable degree of directional work. This rule applies even in the production of small and medium size forging made under production methods in closed dies or as drop forgings. Figures 13 and 14 represent good examples of a properly and improperly forged valve body. These sections have been specially etched to bring out the flow lines. Figure 13 is a section of a valve which failed in service. The pinch effect of flow lines can be clearly noted as probable points of stress concentration.

Figure 14 shows section of a rough forging for the same type of valve having a far more favorable disposition of flow lines which was accomplished by proper design of forging machine dies.

HEAT TREATMENT.

Practically all forgings used in important engineering applications are given some heat treatment after forging. In the early days of application of forgings to Marine and other engineering work, wrought iron or very soft grades of steel were the principal materials used. Heat treatment, if any, consisted of annealing with no precise method of control or no clear ideas of the benefits derived from such treatment, excepting that usually machinability was improved.

With the increasing demand for horsepower, stronger materials were necessary which was met first by increase in carbon content and later by the use of alloy additions. These inherently stronger materials will only develop these maximum properties by very carefully controlled heat treatment. The result is that today the operation of heat treatment is equally as important as those of melting and forging.

Excepting in the case of extremely low carbon soft grades, steel in the condition as forged will vary greatly in hardness

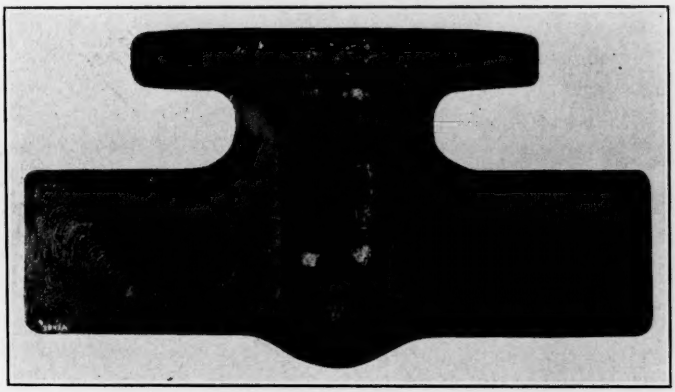


FIG. 14. SECTION OF VALVE FORGING SHOWING SATISFACTORY FLOW LINES.

throughout the piece rendering machining difficult, will be badly strained causing warpage and distortion and will have extremely non-uniform physical characteristics. Proper heat treatment is necessary to correct this condition of non-uniformity and to develop the best physical properties. Heat treatment will vary from simple annealing to various combinations of normalizing, annealing, quenching and tempering or drawing.

The heat treatment to be given a forging is selected with consideration to chemical composition, the size and shape of the forging, the physical characteristics desired and the type of service to which it will be subjected. Methods of heat treatment which are considered standard for small uniform sections of material are generally entirely unsuitable for large forgings, it being necessary in many cases not only to alter the treatment temperature but also to change the entire scheme of heat treatments. It is also a well recognized fact that combinations of physical characteristics which are obtained on small sections of material of a given composition cannot be approached in heavier cross-sections. Generally speaking, the cross-sectional area and uniformity in dimension determines the type of treatment which is safe and effective. The widest latitude of discretion given the producer in selecting combination of alloys in the steel composition, as well as details of heat treatment assists greatly in obtaining the best results.

With the demand for reduction in weight there is a strong temptation among designers to require physical properties on large and important forgings which are incompatible with the greatest degree of safety and service reliability. A properly heat treated forging should have the greatest possible uniformity throughout. The center of a heavy mass is not susceptible to the effect of drastic treatment such as liquid quenching and such treatments result in full treatment effect only on the ends and surface of the piece. While conventional testing methods may indicate excellent physical properties serious internal residual stresses will exist due to extreme non-uniformity. The actual factor of safety of a forging of this character is far less than indicated from results of test.

We have learned a great deal in recent years about the internal characteristics of heavy masses of steel by the taking of deep seated test specimens from heavy forgings such as used in large

power plant machinery. Many specifications for highly stressed forgings for dynamic service now contain clauses forbidding liquid quenching. The best forging for this type of service is one of a composition which is capable of developing the highest possible physical properties in the annealed condition. Such a forging, when properly treated by a combination of normalizing and annealing treatment, will have the best possible characteristics for service. The physical properties as demonstrated by tensile tests may be disappointingly low when compared with the highest values obtainable from the composition applied when treated and tested in small sections, but the actual factor of safety will be far higher than would be the case were the same forging drastically treated for high physical properties.

It is not the purpose of this discussion to condemn liquid quenching as an unsuitable method for heat treatment but rather to urge discretion in its application. There are many forgings of uniform section and of metal thickness that permits uniform treatment for which liquid quenching and drawing is the most desirable treatment. We can cite an example of the influence of design and character of service requirements on heat treatment and specifications in the case of two very important types of Navy forgings, namely, torpedo air flasks and propellor shafts. The torpedo air flask is a relatively thin-walled cylindrical forging of uniform section which is ideal for heat treatment by liquid quenching and drawing. The specifications for this forging require elastic limit of 125,000 pounds per square inch which can be obtained uniformly throughout the forging by quenching and drawing a highly alloyed steel which has received proper conditioning treatments prior to quenching. The service requirements for this forging involve high static stresses with moderate impact requiring relatively less ductility that would be required where dynamic stresses are involved.

In the case of propeller shaft forgings which have a relatively heavy wall with a constricted bore and heavier walls at one or both ends we would hesitate to agree to a specification based on physical properties one-half those required for the air flask forging using the same or any other composition of steel. Liquid quenching of a propeller shaft forging would be a hazardous un-

dertaking and physical test results would be misleading as to the properties of the forging.

Forgings are selected for important engineering application in preference to castings—welded, riveted or mechanically assembled pieces, because they can be made sound throughout, of homogeneous wrought metal texture, and uniform in grain size and physical properties. To obtain the latter properties of uniformity we must rely largely on heat treatment. With alloy steels which are extremely responsive to the effect of heating and cooling it is necessary to select treatment for a piece of given size and cross-section that is relatively effective throughout the mass rather than on the surface only. Any one of a number of commonly used alloy steels are capable of developing a wide range of useful physical properties. While it is possible with a number of types of highly alloyed steels to obtain with safety tensile strength approaching 200,000 pounds per square inch with a suitable elastic ratio on thin section of suitable design, on other pieces of massive section lacking in symmetrical proportions, we would hesitate to offer values much over 100,000 pounds per square inch tensile strength using the same steel with any certainty of having desirable degree of uniformity.

Alloy steel is one of the greatest metallurgical developments of the present age and when properly applied has an unlimited field of usefulness. It is believed that much of the prejudice existing in some quarters against its use is the result of unwise application of the material.

SPECIFICATIONS.

The preparation of standard specifications covering under one heading various sizes and types of forgings is an extremely difficult task as requirements and restrictions which are entirely proper for one type are inapplicable for others. The Navy specification for forgings (49-S-2), while by no means perfect, represents a remarkably good type of specification when consideration is given to the large variety of forged products which it covers. The general requirements for propelling machinery forgings which designate location of test specimens on various types of forgings—is

remarkably clear. This specification, like any other broad standard, while imposing needlessly severe restriction on some types of products, is not sufficiently exacting on others.

There is a growing tendency among many users of high grade forgings, either to prepare separate leaflet specifications for each major type of forging or to insert special requirements on the drawings which is generally preferable to attempting too comprehensive a coverage in one standard specification.

A serious fault in many standard specifications is inclusion of tables of physical properties which are based on average values obtainable, but which are specified as minimum requirements, used as a basis for acceptance or rejection. In the case of large forgings this presents serious difficulties through necessity to retreat product, which is equal in physical properties to some of the forgings used as a basis for formulating the specifications. With such a situation there is a strong temptation for the manufacturer to alter heat treatment to meet the requirements of the specification with a safe margin, possibly resulting in less desirable treatment than was given the material on which the specification was based.

As a general practice, actual physical properties of forgings will be kept from 10 per cent to 20 per cent in excess of the rejection limits specified as a manufacturing safety factor so as to prevent the necessity for frequent retreatments. If minimum values, rather than averages for the class of material desired, were used as a basis for establishing rejection limits the original intent of the specification would be realized and in many cases considerable money would be saved to the consumer.

It is believed that the service which producers of forgings are rendering the industry could be greatly improved through closer cooperation between the designer and forging producer during the process of development. In many cases a better knowledge by each party of the other's problems would result in development of design and specification which would not only save needless cost but would result in a more serviceable finished product.

NOTES ON THE HISTORY OF LUBRICATION.

Part II. Journal Bearing Experiments.*

By Mayo D. Hersey.†

Quantitative experiments on journal bearings, in the modern sense, may be considered to have begun with Kingsbury's study of the air-lubricated journal (Ref. 1),‡ published by the American Society of Naval Engineers in 1897. This investigation is one of the few in which friction, film thickness, and pressure distribution have all been measured; and in which the friction torque observed was that acting on the journal, rather than on the bearing. As pointed out later by Harrison, in his theoretical work which is to be reviewed in Part IV, the difference between the two torques may under some conditions be relatively great. It is, in fact, equal to the product of the load on the bearing by the component of the eccentricity perpendicular to the line of action of the load. For the purpose of computing the power dissipated in friction, it is necessary to know the friction torque acting on the moving rather than on the stationary part.

In reviewing the published work on journal bearing lubrication during the first third of the twentieth century, it will be found convenient to discuss the various contributions from the standpoint of the principal performance observations that have been undertaken—friction, film thickness, pressure distribution, temperature rise, flow characteristics, load capacity, wear, shaft vibrations, and changes occurring in the lubricant.

Table I may be found useful in locating the references corresponding to any particular investigation.

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* Part I, General Survey, appeared in the November, 1933, issue. Parts III and IV, to be published later, deal with Physical Properties of Lubricants, and Development of the Theory of Lubrication, respectively.

† Division of Engineering, Brown University, Providence, R. I.

‡ References to publications will be found at the end of the article and, as before, have been grouped chronologically by years, and arranged alphabetically by authors within any one year.

TABLE I. GUIDE TO JOURNAL BEARING DATA.*

Almen 83, Archbutt 48. Atwater 86.—Barber 105, Barnard 31, 38, 40, Basil 111, Biel 15, Bochet 9 (I), Boswall 29, 87, Bradford 71, 79, 80, 88, Brierley 87, Büche 81, Busse 89.—Charnock 61, Clower 106, Couette 31 (I).—Dahlstrom 107, Davenport 88, 105, Deeley 48, de Forest 13, Defossez 25, Denton, J. M. 33 (I), Denton, W. H. 90, Deprez 19 (I), Dettmar 41 (I), Duffing 23, 53.—Ellis 74, vom Ende 54.—Falz 108, Forrest 38.—Gilson 42, Goodman 28 (I), 62, 109, Gordon 110, Grobel 119, Grunder 71, Gümbel 11, 14, 21.—Hanocq 63, Harrington 118, Heimann 6, Hein 90, Hensel 91, Herschel 24, 32, Herschman 111, Hersey 9, 12, 33, Herttrich 64, Heyd 55, Hirn 8 (I), Hodgkinson 65, Hohenschutz 112, Howe 120, Hummel 43, Hyde 17, 18.—Jakeman 72, Jaquerod 25, Jervis 8, Job 113.—Kammerer 19, Karelitz 44, 56, 73, 74, Kelso 10, Kieser 22, Kimball 12 (I), King 114, Kingsbury 51 (I), 70 (I), 1, 4, 7, 115, Kluge 70, 82, 102, Köhler 57, Kyropoulos 92, 116.—Larson 117, Lasche 2, 22, 34, Lewis 58, Linckh 82, Linsley 39.—Marx 93, Massey 29, Maurer 10, McKee, S. A. 45, 49, 50, 66, 68, 94, 95, 118, McKee, T. R. 66, 94, 95, 118, Michell 67, Moore 5, Morin 6 (I), Mougey 75, 83, 104, Mügeli 25, Myers 38.—Neeley 96, Newkirk 41, 97, 119, Nücker 98.—O'Neill 84.—Petroff 20 (I), 26 (I), 29 (I), Ponomareff 120.—Ry. Mech. Eng. 85.—Schein 121, Schenfer 26, Schering 46, Schmitt 99, Schneider 76, 78, Soc. Gén. Isothermos 100, Stanton 16, 27, 28, 51, 59, Stoney 29, Stribeck 3.—Taylor, G. I. 35, Taylor, H. D. 41, Thomas 10, Thurston 13 (I), 14 (I), 23 (I), Tichvinsky 91, Tower 18 (I), 24 (I).—Vieweg, R. 37, 46, 47, 52, Vieweg, V. 20, 30, 36, 37, 47, 52, 69, 70, 77, 101, 102.—Walger 78, 103, Wellington 22 (I), Weber 19, Welter 19, Wilson 31, Wolf 104, Wolff 60.

* References to Part I are distinguished by the Roman numeral (I).

FRICTION MEASUREMENTS.

Lasche reported the results of his experiments on certain high speed bearings with different clearances in 1902, including temperature observations. Stribeck's work on bronze and white metal bearings which is so often quoted was conducted in Germany at about the same time, and is of special interest because of the very wide range of observations on both sides of the minimum point. Confirmatory data were obtained by Heimann.

Friction observations on a journal of 1⅜ inches diameter were included in Kingsbury's paper of 1903. Friction tests on shaft bearings up to 15 inches diameter were reported in 1906, including also film thickness and temperature measurements. It was found possible to run these bearings with loads and speeds greatly exceeding the ordinary values adopted in practice.

The contrast between friction curves for lard oil and mineral oil when plotted against temperature was clearly shown in a report by Jervis in 1907. These tests were conducted by a student of the Worcester Polytechnic Institute using the Kingsbury oil testing machine with journal diameter of about 1⅜ inches.

Practical tests at the University of Wisconsin on ring-oiled, babbitted line shaft bearings in comparison with other types were reported by Thomas, Maurer, and Kelso in 1913.

The author's experiments on a full journal bearing at the Massachusetts Institute of Technology, using both mineral and fatty oils, were published in 1914. These experiments led to a simple linear relation, with two constants, connecting the coefficient of friction with the product of the viscosity into the speed divided by the load, applicable under thick film conditions. The effect of restricting the oil supply was also investigated.

Biel's experiments which had been conducted at Karlsruhe with an electrically polymerized oil and an ordinary mineral oil were published in 1920. In the same year there appeared a report of the bearing investigations at the Technischen Hochschule in Berlin by Kammerer, Welter, and Weber, and two reports of work conducted by Stanton and Hyde at the National Physical Laboratory in England.

The experiments by Jaquerod, Debossez and Mügeli at Neuchâtel published in 1922 are of unusual interest in showing that the same

general relations connecting the coefficient of friction with speed, viscosity, and other factors which have been established theoretically and practically for the largest bearings, are equally valid for the small journal bearings of clock and watch mechanisms.

Note may be made of friction investigations by Duffing, Herschel, and Stanton, also one by Stoney, Boswall, and Massey appearing in 1922. During the same year Wilson and Barnard presented their graphical coordination of previous data, together with hitherto unpublished tests by Hayward on a Thurston type Riehle machine.

Every edition of Archbutt and Deeley's treatise contains a useful chapter describing the numerous oil testing machines, such as the Thurston machine which is so well known in the United States, and the Martens machine which has been widely used in Germany. Herschel, however, concluded from his experiments published in 1923 that the journal bearing does not represent the most suitable design of rubbing surface for use in comparative testing of oils, and since then journal bearing observations have been more frequently looked upon as a means for obtaining information about bearing performance than as a means for studying the physical properties of lubricants.

A novel method for distinguishing between windage resistance and bearing friction was described by V. Vieweg and R. Vieweg in 1923. A report followed by V. Vieweg on the status of lubrication research at the Reichsanstalt, the German government laboratory in Berlin. This brings our narrative up to the close of the year 1923.

Not less than fifty investigations including friction measurements on journal bearings have appeared in the past ten years, comprising about two-thirds of the remaining references at the end of the article. Of these it need only be stated here that they covered a wide variety of test conditions, and brought forth some extremely interesting improvements in technique. They should, of course, be carefully examined by anyone contemplating further experimental work.

FILM THICKNESS.

The film thickness at point of nearest approach may be computed from the eccentricity of the journal relative to the bearing, and vice versa. Observations with radially placed micrometers or

the equivalent were published by Kingsbury* in 1906; Gümbel in 1914; Stanton in 1922; Stoney, Boswall and Massey in 1922; Goodman* in 1929 and 1933; Bradford and associates in 1930, 1931, and 1932; Barber and Davenport, Boswall and Brierley, and Marx and associates† in 1933.

The tapered plug principle for film thickness or clearance measurement in unloaded vertical bearings was applied by Kingsbury in experiments reported in 1919 and 1933, and by Kyropoulos in his papers of 1932 and 1933.

Formulas for determining eccentricity and film thickness electrically were published by the author in 1910. The capacitance method was used successfully by Schering and R. Vieweg in 1926, and by Nücker in 1932. The resistance method was used by Hein in 1932. An electromagnetic method due to M. Stone was described by Karelitz in 1930 and more fully by Tichvinsky‡ in 1933. A piezo-electric method was applied by Kluge and Linckh, 1931.

Two optical methods were developed by V. Vieweg and A. Wettauer, 1922, the first utilizing a revolving grating attached to the end of the shaft, the second involving diffraction of a ray of light passing over the top of the shaft. Results obtained with the diffraction method were further described by V. Vieweg in 1923. A method based on interference fringes was applied by Wolff in his experiments at Göttingen for the German railways, 1928. An optical device especially adapted for indicating vibrations was described by Newkirk and Grobel, 1933.

PRESSURE DISTRIBUTION.

Since the publication of Kingsbury's experiments on the air-lubricated bearing, seven different laboratories have contributed to our knowledge of the true hydrostatic pressures in the film: (1) Gümbel, 1914; (2) Stanton, two papers, 1922; (3) Goodman, 1929 and 1933; (4) Bradford and Grunder, 1930; Bradford, two papers, 1931; Bradford and Davenport, 1932; Barber and Davenport, 1933; (5) McKee, S. A. and McKee, T. R., 1932; (6) Nücker, 1932; (7) Newkirk and Grobel, 1933. Stanton's experiments are

* See also Refs. 1 and 28 (I).

† See also Green, B. M. Bearing lubrication. Jour. A. S. M. E., April, 1917, pp. 320-322.

‡ Tichvinsky, L. M. Discussion of Barber and Davenport's paper, pp. 46-47.

of special interest because of the extremely high pressures reached. To reconcile the results with the hydrodynamic theory it was necessary to take into account the increase in viscosity of lubricants under pressure. The McKee investigation is of interest because of the simplicity of the laboratory set-up, and the precision of the observations. Nücker's tests were made on large diameter bearings, with simultaneous measurements of the temperature distribution.

TEMPERATURE RISE.

Measurements of temperature rise, temperature distribution, or heat transmission played an essential part in the work of Lasche, 1902 and 1921; Kingsbury, 1906 and 1933; Welter and Weber, 1920; Stanton, 1920 and 1927; Karelitz, 1926 and 1930; Charnock, Hodgkinson, 1929; Karelitz and Ellis, 1930; Boswall and Brierley, Nücker, 1932; Clower, Falz, Gordon, Hohenschutz, 1933.

The experiments of Lasche and of Karelitz are of special interest in determining the rate of heat transmission from a bearing to its surroundings at any given temperature; those of Nücker in connection with the temperature distribution over the bearing surfaces; while Kingsbury in his most recent experiments investigated the internal temperature distribution in the film.

FLOW CHARACTERISTICS.

Hyde observed the flow configuration by means of a glass bearing; his report was published in 1920. The rate of oil flow through journal bearings as affected by speed, load, and viscosity was investigated by Barnard, 1925; Boswall and Brierley, 1932; and by Nücker, 1932. Karelitz studied the delivery of oil to the journal by capillary action in waste-packed bearings, 1926 and 1928; and by the action of the rings in oil-ring bearings, 1930.

Couette's problem of the critical speed for turbulent motion between concentric cylinders was very completely solved by the experiments of Taylor, published in 1923, and confirmed by Lewis, 1928.

LOAD CAPACITY.

Bearings are ordinarily operated with a considerable factor of safety. Hence, for purposes of design the load capacity or permissible bearing pressure is normally computed either from (*a*)

film thickness data, or (*b*) location of the minimum point on the friction curve. When a direct observation of bearing failure is desired, other methods are necessary.

Mechanical methods based on a sudden jump in the friction torque, sometimes accompanied by other seizure effects have been described by Herschel in 1923; Linsley, 1924; Mougey, 1930; Mougey and Almen, 1931; Wolf and Mougey, 1932; Larson, 1933; McKee, Harrington and McKee, 1933.*

Load capacity tests using the electrical resistance method were reported by Moore in 1903; by the author, 1914 and 1923; de Forest, 1916; Biel, 1920; Schenfer, 1922; Linsley, 1924. A simple demonstration by means of an electric lamp in series with the oil film was set up by S. A. McKee at the Bureau of Standards and described in 1929. This working model is so designed as to show the effects of varying the speed, the load, and the angular position of the oil inlet.

WEAR OF JOURNAL BEARINGS.

The more recent experiments on the wear of bearing surfaces may be reviewed in three groups, (1) general studies on the mechanics of wear, (2) comparative tests on bearing metals, and (3) development of non-metallic bearings.

The effect of repeated deformations on wear was demonstrated by Karelitz in 1926. An investigation of running-in, showing that the minimum point on the coefficient of friction curve is progressively shifted towards lower speeds and heavier loads, was presented by S. A. McKee in 1927. In the same year R. Vieweg and V. Vieweg discussed means for increasing the load capacity, and reducing the wear, of oscillating and slowly moving machinery. This was accomplished by giving a sufficient velocity to some of the supporting parts that would ordinarily remain stationary. Dahlstrom, in a report published in 1933, described an oil-lubricated bearing for roll-necks which offers good evidence for the belief that the wear problem in steel mills can be overcome by rational design of bearings.

* See also Ref. 88 (I), later published in Jour. S. A. E., vol. 33, Dec., 1933, pp. 402-408.

Bearing metals for roll-necks were investigated by Heyd in a comprehensive report appearing in 1928. For other studies of bearing alloys in actual journal bearing service reference is made to papers by Karelitz and Ellis, 1930; Hensel and Tichvinsky, 1932; Herschman and Basil, 1933.

Non-metallic bearings of modern design have been described by Atwater; Busse and Denton; Newkirk; and Schmitt in papers published during 1932. The experiments on water-lubricated soft rubber bearings gave results in accord with the theory of lubrication.

SHAFT VIBRATIONS.

Vibrations of the journal due to yielding of the lubricant in conjunction with the elasticity of the shaft in high speed bearings were reported by Newkirk and Taylor in 1925. A similar phenomenon due solely to the viscosity of the lubricant, without regard to elastic deformations of the shaft, had been predicted by Stodola and was investigated by Hummel, at Zurich, in a paper published in 1926. The problem was further studied at Schenectady and a practical solution presented by Newkirk and Grobel in 1932.

CHANGES IN THE LUBRICANT.

A question frequently investigated in the practical operation of steam turbines and internal combustion engines is that of changes occurring in the oil due to the temperatures and other conditions experienced in service. One of the most familiar changes is that of increased viscosity due to oxidation. An interesting example was cited by Karelitz in his paper of 1926. Tests for determining such changes after the oil has been used for a prescribed length of time in a journal bearing machine are conducted by the Engineering Experiment Station at Annapolis. This machine has been described by O'Neill in a paper published in 1931.* Other conditions being equal, the oil which shows the greater oxidation is considered inferior. Paradoxically, the beneficial effects of oxidation in journal bearings have been emphasized in a report of re-

* See also Tech. Bull. 18, School of Eng., Penn. State College, 1933, pp. 5-26.

search by King, 1933. It would appear that the seemingly divergent results of these investigations might be reconciled by taking into account the factor of oiliness and the effect of running-in.

CONCLUSION.

The results of the journal bearing experiments will be further considered in Part IV. They are in accord with the theory of lubrication so far as it has yet been developed, and provide many important facts to be taken into account in the future extension of the theory.

Table II shows the chronological distribution of journal bearing publications cited in Parts I and II, from which it will be seen that the output is undergoing a surprising acceleration, with 43 contributions in the last 3-year interval as compared with 38 in the preceding 5 years. Thus it appears that the task confronting any individual or committee undertaking to coordinate the current information during the next few years is not a simple one.

TABLE II. CHRONOLOGICAL DISTRIBUTION.

Period	Number	Period	Number
1831-1840	1	1901-1905	5
1841-1850	0	1906-1910	3
1851-1860	1	1911-1915	3
1861-1870	0	1916-1920	9
1871-1880	3	1921-1925	21
1881-1890	10	1926-1930	38
1891-1900	3	1931-1933	43

To the student or professional engineer now entering upon a serious study of lubrication for the first time, the task may seem bewildering. It is suggested, however, that no mistake will be made in beginning with a study of the experiments conducted by Hanocq at Liège, Büche at Karlsruhe, the Vieweg brothers at Berlin, Nücker at Darmstadt, and by Kingsbury and by the McKee brothers in the United States.

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3. Stribeck, R. Die wesentlichen Eigenschaften der Gleit und Rollenlager (Characteristics of plain and roller bearings). Zeit. V. D. I., Bd. 46, 1902, pp. 1341-1348, 1432-1438, 1463-1470.

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THE ENGINEER AND MODERN CIVILIZATION.*

By Sir Frank Smith, K.C.B., F.R.S.

INTRODUCTION.

I am greatly honored by the invitation extended to me to address this distinguished gathering. The subject of the address was left entirely open to me, and for a long time I hesitated; should I speak to you on a special branch of engineering, as past Gustave Canet lectures have done, or should I address you on some more general aspect? Before deciding, I read once again the addresses of past Gustave Canet lectures; Sir Trevor Dawson's paper on "The Engineering of Ordnance" I thought most appropriate for the occasion, and I was tempted to address you on an allied subject, namely, "Engineering Ballistics," a subject of which I have some knowledge. An alternative subject was that most remarkable artillery of all, the disintegrating radium particle, which sends out its projectiles at many thousands of miles a second. But I concluded that such a subject would be of too specialized a character, and eventually I decided to choose a very general subject and to address you on "The Engineer and Modern Civilization."

I cannot, of course, do more than touch on a few of the more important aspects as I see them. I shall endeavor, in the first place, to give you my impressions of the engineer of today and compare him with the engineer of hundreds of years ago; then I shall present a brief record of achievements of the civil, mechanical, and electrical engineers; a kind of quantitative picture of the materialistic culture of our time which has resulted from their labors. Finally, I shall describe the scientific evolution of the steam engine and internal combustion engine and the engineer's part in increasing food supplies.

THE ENGINEER OF TODAY.

For some time I was at a loss how to define the engineer of today, but eventually I found that Lord Macaulay, over a hundred years ago, had described the man about whom I wish to speak as "he who molds things" in contradistinction to the philosopher, whose object was "only to mold words." Before Macaulay's day, and before science had gained any appreciable status, the engineer had "molded things"; he had constructed magnificent roads, built fine waterways, erected massive cathedrals, extracted metals from their ores, invented valuable tools such as the lathe, and built carriages and ships. All these were done without a knowledge of science, and one can but conclude that the structural engineer of early times, either consciously or subconsciously, followed the principles which nature pursues in creating her own structures. If we examine one of nature's structures, such as that of a corn stalk, or the shell of a snail, or the wings of a bat, we observe that nature designs her structures with a minimum of material to withstand the stresses to be borne, and the most expert mechanical engineer of today, if he possessed complete knowledge of the mechanism of stress and was aware of all the properties of all materials, would probably be able to design nothing so good and certainly nothing better for the purpose than the shell of a snail. No doubt our engineer forefathers possessed also that wonderful intuition which so many engineers possess today, and no doubt they profited by their failures as well as by their successes. We know that they made mistakes at times; their bridges collapsed and the roofs of their temples fell in, but none so far as I know made mistakes of such magnitude as those

* Junior Institution of Engineers, Gustave Canet Lecture, June 28th, 1934.

set by Gulliver in his imaginary travels. If Gulliver had really met giant men they would have been robots of steel, for nature, with bone as her structural material, would never have designed man magnified ten times knowing that such men would not be able to walk. It is indeed questionable whether man, if magnified ten times in height, breadth, and width, would be able to support comfortably his 50 tons weight on his legs of bone, let alone walk. Our forefathers apparently knew this and the modern engineer is well aware of the fact and has discarded wood for steel in order to build bridges of great span. But he knows that there is a dimensional restriction on steel bridges, as on the size of man with bone, and new and better steels are required before the engineer can contemplate much greater structures than that of the Sydney Harbor Bridge.

But the engineer of today is distinguished from his predecessor inasmuch as he is studying structures of ultra-microscopic size as well as those of gigantic proportions. He knows that the properties of any material depend on the properties of the ultimate units of which the material is built. He is no longer satisfied to measure the hardness of a metal like pure copper, but he wishes to know why its hardness is what it is. Also why when copper is alloyed with tin the resulting bronze is harder than either the copper or tin of which it is composed. The engineer of Macaulay's day was satisfied with the fact that the bronze was harder; today, the engineer seeks to find out why, knowing that with such information he will be able to produce even better structural materials than those now in use.

Again our forefathers were aware of nature's great demonstration of an electrical discharge, namely, lightning, and those who studied electrical and magnetic phenomena showed how high voltages and electrical discharges could be produced in the laboratory. Thus they were able to explain how lightning was caused. But it was not until after the ultimate unit of electricity, the electron, had been discovered by those seeking the structure of matter that we became aware of those great electrified regions surrounding the earth which form the permanent way over which our trains of wireless waves travel and a knowledge of which is so valuable to the wireless engineer. Fifty years ago the electrical engineer was content with a knowledge of Ohm's law and the experimental fact that in general a metal, when cold, conducts electricity better than when it is hot. Today we are not so content; we want to know why this difference exists, and to obtain the knowledge we must go to the atoms which comprise the metal and to the electron itself, and the engineer is finding out why. We need not ask "Is it worth while?" for past experience shows that it is. Years ago, when it was found that light incident on a metal surface made it lose a negative charge, the fact appeared to be of trivial importance. The engineer had to go to the atom to find out why, and when he had found out all he could the results were applied to the talking picture and other industries.

The chemical engineer, like the electrical engineer, is today very anxious to know more of the structure of his material. Chemistry itself was not on a quantitative basis until John Dalton gave us the atomic theory. Dalton was considering the ultimate structure of the elements. Later, by the scientific study of chemical reactions and examination of the products, the chemical industry was built up. Today, the chemist is asking questions about the ultimate units of his elements and compounds. He wishes to find out the mechanism of chemical change. Years ago he believed he knew the composition of water, but the chemist of today has gone over the ground again and discovered heavy hydrogen. What its industrial uses may be I do not know, but the chemical engineer is preparing to make it in quantity ready for the day.

Catalysts have been known for many decades, but knowledge of the mechanism of catalysis is far from satisfactory. In the production of fixed nitrogen

from the air I understand that thousands of catalysis were tried. It was a case of trial and error. Had the nature of catalysis been better understood, it is certain that much of this experimental work would have been unnecessary, and when we know more fully how and why catalytic reactions take place, it is highly probable that many catalytic processes in operation today will be replaced by processes which are better and cheaper. The chemist of 100 years ago differed from the chemist of today; our modern chemist not only produces a large variety of chemical goods by well-controlled chemical reactions, but he is seeking the reasons for the changes which occur, and in his investigations he is employing X-rays, infra-red spectra, and other tools provided for him by the engineer who studies atoms.

Because of such things the engineer of today is better defined not only as one who molds things with his hands, but as one who also studies nature and molds things in accordance with the facts learned. The engineer as thus defined includes the scientist working in his laboratory as much as the engineer who was responsible for the erection of the Forth Bridge.

MODERN CIVILIZATION.

As for modern civilization, it is impossible for me to sum it up as briefly as I have described the engineer. Modern civilization is a very complex structure, made up not only of contributions of the engineer, but also of much less easily defined contributions of an idealistic character. The engineering culture embraces the sciences, industry and commerce, and the idealistic culture includes the fine arts and philosophy. It is a blend of these two cultures which forms the civilization of today, but the materialistic culture is much more advanced than ever before, and it is this which distinguishes so markedly our modern civilization from that of a hundred years ago, and even from that when this institution was formed fifty years ago.

When the historian paints the materialistic side of our civilization, he will, no doubt, emphasize that the agrarian pursuits of the people are no longer predominant, and that the main feature of our civilization is the mechanization of practically all our industries, including agriculture. He will, no doubt, describe the great liners bringing meat and fruit of all kinds to our shores in all seasons of the year, and from all parts of the world; he will paint pictures of our water supplies, and of our sanitary services; of the development of rail and road transport; of our iron and steel works producing girders for the building of offices in our industrial towns; of our concrete roads and bridges built for rapid transport of people, both on pleasure and on business; of our streets lit up brilliantly with electricity and with compressed gas; of the glaring neon signs, such as are seen in Piccadilly-circus; of our rapid means of communication with people in all parts of the world; of our aeroplanes, and of other things, such as our picture theaters.

The historian will, no doubt, claim for the engineer that he has made available almost unlimited quantities of energy from coal and oil, and high-level water, to aid man in the production of commodities even to a surplus; that he increased the standard of living; gave more leisure to all classes, and helped to eradicate many diseases, such as cholera, by the excellence of his water supplies and his sanitary works.

The composite picture of these many aspects of our civilization is, indeed, a complex one. Many call it the second industrial revolution, but the structure on which it is based is the same as that of the first industrial revolution, namely, the prime mover. Some there are who call it the age of flying, or that of the motor car, or of the automatic machine. Others call it the age of electricity. It is, I think, well to examine the picture more carefully to see if there are any outstanding features not readily seen by the untrained eye.

There are some who ask whether the picture is made up of accidental happenings. I think the reply to these is best given by looking at the picture through glasses of various tints. Let us look at it first through the spectacles of the electrical engineer, the civil engineer, and the mechanical engineer.

THE PICTURE OF THE ELECTRICAL ENGINEER.

If an electrical engineer were asked to describe the engineer's picture of today, he would probably disregard all that portion of the picture more than a hundred and fifty years old. He would emphasize, as well he might, that it is only a little more than a hundred years ago—in November, 1831, to be exact—that Faraday discovered the principle of electro-magnetic induction, and on this principle all modern electric motors and dynamos are based. How much electrical machinery there is in use in this country today I do not know, but the electrical engineer would probably tell us that in 1930, the last year for which we have complete returns, the output of electrical machinery in Great Britain was valued at over £21,000,000, compared with something practically zero fifty years ago, and the total output of the principal electrical products exceeded 77 million pounds. He would probably call attention to the work of Maxwell, who studied Faraday's results, and put forward the theory that light was an electro-magnetic phenomenon. Hertz, you will remember, demonstrated that validity of Maxwell's theory, and this led, through Marconi, Lodge, and others, to wireless telegraphy and telephony, that wonderful development which has made the world seem so very small. Of wireless apparatus alone, excluding valves, nearly £7,000,000 worth were made in Great Britain in 1930, and over £6,000,000 worth of primary batteries and accumulators were constructed. The electrical engineer would also probably remind us of the discovery of the electron by Sir Joseph Thomson, and the way it insists on a one-way traffic route in rectifiers. The electric lamp he would claim as a very modern creation, incorporating the discoveries of Sir Joseph Thomson, of Rayleigh, of Ramsay, of Langmuir, and the inventive genius of Edison and Swan. The electric arc which preceded it was generous in its light, but troublesome in its maintenance, and had to be kept out of doors, and even then it was not used extensively. Today's gas-filled filament lamp, while it seems a simple device, probably represents the results of more research on the structure of matter than any other single article in common use. The original carbon filament lamp appeared fairly perfect fifty-three years ago when Lord Kelvin lighted his house with lamps made by Swan, the current being obtained from a battery charged by a dynamo of which the prime mover was a 2-cycle gas engine of the Dugald Clark type. That lamp which Kelvin had would be termed most wasteful today, for the power it consumed would, in a modern vapor lamp, give out sixteen times as much light. Strange it is that fifty years ago, argon, although a constituent of our atmosphere, had not been discovered; Rayleigh and Ramsay were engaged in studying the structure of air, and discovered it; today, it is in use in many millions of electric lamps—indeed, tens of millions are made in this country every year. The electrical engineer would remark with pride that the whole of the underground railways of London are run on electric power, that broadcasting and the telegraph are electrical, and that the kinematograph and the talking picture are largely products of his creation. Finally, he would point out that the country is covered by an electric grid of 4000 route miles, and the generation of electricity in 1932 amounted to over 13,500 million units. Electrical engineering fifty years ago was of negligible magnitude. Surely, says the electrical engineer, this is the age of electricity, and the picture of engineering achievements of today is predominantly electrical.

THE PICTURE OF THE CIVIL ENGINEER.

The civil engineer would describe a very different kind of picture. The scientific discoveries which led to the birth of electrical engineering find no parallel in civil engineering. Long before the dawn of the Christian era there were irrigation works, water works, and good roads in Mesopotamia, in Egypt, and in the Roman Empire, and the civil engineer is fortunate in having the accumulated experience of thousands of years to guide him. Compared with the products of the electrical engineer, the size of many civil engineering works is colossal. The civil engineer would point with pride to such examples of his work as the dam and canal system in the Sudan, by means of which over 300,000 acres of cotton-growing land have been brought into cultivation. This scheme, he would tell us, provides for the storage of 600,000,000 tons of water without any injury to Egyptian water supplies, and if costs are any indication of value, he would tell us that the scheme cost £9,000,000. In India the risk of famine for a huge population has been removed by irrigation schemes serving an area of over 30,000,000 acres, and in Australia, the civil engineer has completed the Dawson Valley scheme, which forms a water reservoir impounding 3,100,000,000 tons of water. In this country no better example of the engineer's services to man can be found than in the reduction of epidemics due to waterborne disease, resulting from the improvement in water supplies and in sanitation. I do not want to suggest, of course, that our water supplies are even yet adequate or that there are no great problems for the engineer, biologist, and chemist in meeting the ever-increasing demands for water which the development of industry and the rise in the standard of living of the people are constantly making. There is, of course, much still to be done, as the anxieties which we are passing through in connection with the drought so clearly show. More reliable data, for example, are badly needed of the actual amount of potential water supplies available in this country. Such data could be obtained from river gaging on a wide scale, so that we should have exact information regarding the amount of water available in our rivers at different seasons of the year. One has only to survey, however briefly, what has been done to realize what the state of the country would have been if it had not been for the efforts of the engineer. Take, for example, the Metropolitan Water Board, which has incurred a capital expenditure of more than £50,000,000 in order to supply 280,000,000 gallons of water per day through its 7400 miles of distribution and service mains to the 7,000,000 people in the London area. Water for this supply is drawn from the Thames, the River Lea, and fifty-seven wells and springs. The various works include forty-nine large reservoirs with a total area of 2700 acres and a storage capacity of nearly 20,000,000,000 gallons. There are 117 pumping stations and ninety-four service reservoirs. The water has to be purified before distribution by physical, chemical, and biological processes, such as filtration and treatment with chlorine to insure that the water reaching the consumer is of good quality. In all this work it is the engineer who has made possible of application the researches of the chemist and bacteriologist. There are many other instances of the work of the engineer in great schemes of water supply; for example, the water for Manchester is conveyed about 100 miles from the Lake District, and Birmingham obtains water from the Elan Valley at a distance of 74 miles.

In the field of sewage disposal the work of the Birmingham, Tame and Rea District Drainage Board is one of many examples of service to the community resulting from the engineer's utilization of the discoveries of the chemist and biologist. This undertaking deals with a dry weather flow of 35 million gallons of sewage per day from an area of 157 square miles with a population of about 1,200,000. The sewage is subjected to a system of purification, in-

cluding processes of mechanical screening and sedimentation, and oxidation by the biochemical activities of bacteria in the presence of air. One development during recent years is the anaerobic fermentation of separated sewage sludge by means of bacteria with the object of reducing the quantity of sludge and improving its character. During this process methane gas is evolved and at Birmingham the gas is utilized in engines to develop more than 1000 H.P. and thus to supply the power requirements of the works.

It may be interesting also to mention that domestic refuse in England alone amounts to 12 million tons and costs 7s. to 9s. per ton for disposal. It has been calculated that if it were used for generating electricity most municipalities could save 4s. to 6s. a ton and could feed electricity into the grid at less than 0.2d. per unit.

The civil engineer would tell us of the great harbors of the world he has constructed, which are so necessary for the transport of manufactured goods and of food. He would point to our main roads, our railways, and the immense bridges he has built, such as that spanning the Forth and that of Sydney Harbor. Such bridges could not have been built in Roman times or even a hundred years ago. And whatever the old Roman roads were like, it is recorded that at the beginning of last century the main roads to London were leveled in the spring by means of plows drawn by eight or ten horses, and in this state they remained until the following autumn.

THE PICTURE OF THE MECHANICAL ENGINEER.

The mechanical engineer would look at the materialistic picture with the eye of a general contributor. All the machinery used by the electrical engineer, the civil engineer, the chemical engineer, the motor engineer, and others is produced and operated by the mechanical engineer. The ancestry of the mechanical engineer is of very great interest. The electrical engineer did not exist 150 years ago, for though electricity was known, no one had discovered the principles on which electrical machinery could be based. The mechanical engineer, however, could point to the development of his present-day picture with pride and show that for centuries past his predecessors had good mechanical principles, but the materials with which they had to work were poor.

The wheel and axle, the lever, the pulley, and the screw were known in prehistorical times, and windmills and water wheels are so old that it is difficult to say when they were introduced. But it is not these inventions of the mechanical engineer that have affected our modern civilization. It is the machine such as that which Arkwright invented for the textile industry, and more particularly the machines for mass production that have had such a marked effect. The mechanical engineer would tell us how primitive forms of lathe were used for centuries, but no all-metal lathe was constructed until Maudslay invented the slide rest and made the lathe an instrument of precision. The importance of the screw in mechanisms of today is difficult to overestimate, and we owe much to Maudslay, who introduced the exact scientific screw system which was later developed by Joseph Whitworth. Whitworth also created a true straight edge and a true plane surface, and made practicable the standards and gages which are now so familiar in all engineering workshops. Before the time of Whitworth machines and machine tools were such that if the internal combustion engine had been invented it could not have been made even if steel and all the necessary alloys had been available.

Nasmyth constructed the steam hammer for large power work, and Whitney first set up machinery for manufacturing small arms on the interchangeable principle. The mechanical engineer would surprise some of us when he told us that quantity production is more than two hundred years old, for Polhen, a Swede, manufactured more than two centuries ago plowshares,

hammer heads, clock wheels, and other articles by quantity production machinery. An even more interesting example is that of Brunel and Bentham, who, in 1808, manufactured all the wooden blocks for the navy, the output being more than 130,000 blocks per year, valued at over £250,000. The blocks were made by the use of forty-four machines for sawing, boring, shaping, etc., and ten unskilled men did the work formerly performed by 110 skilled workers. Achievements of this kind are very common today, but few, I think, know of this remarkable performance of a hundred years ago.

Today quantity production is largely practiced with special purpose machines having many tools operating simultaneously. No product is too small or too large for the mechanical engineer to deal with. The pin was probably the first mass-produced article; today the motor car is one of the commonest. Surely, says the mechanical engineer, to the composite engineering picture of today the mechanical engineer has contributed most. His products for 1930 were valued at over 128 million pounds in Great Britain alone. The motor car and the aeroplane are his recent and very special products, yet their influence is so vast that many there are who would call this the motor age, or even the age of flying. One has not got to go back so far as fifty years to find Wilbur and Orville Wright building their first flying machine and making more than a hundred successful flights. It was only twenty-eight years ago that Santos Dumont made history by flying a distance of 100 miles, and only twenty-six years ago since Henry Farman won a prize of £2000 for a sensational flight of 1000 miles. Today the flying of the Atlantic Ocean attracts but little attention and flights at altitudes of 18,000 feet and endurance flights of twenty-four hours are not regarded as extraordinary. It is remarkable, say our aeronautical friends, that in such a short space of time the aeronautical engineer should have organized successfully regular air services across every continent and even across the South Atlantic. This age, says the aeronautical engineer, is surely the age of flying.

A somewhat similar, but even more amazing, story is that told by the motor-car engineer. Again we need not go back fifty years to find John Knight, who built a four-wheel car in 1895, being prosecuted by the police for traveling at a speed of 8 miles an hour, which was twice the speed allowed by law. In the thirty-nine years that have elapsed since that day the motor engineer has produced tens of millions of motor cars, and one firm alone in this country can and does produce at times 2000 cars per week, say, two every three minutes of the working day. The rated horsepower of cars in this country is about 27 millions. Surely, says the motor-car engineer, this is the age of the internal combustion engine.

Such are a few of the engineer's contributions to the materialistic side of the culture of today. There are, of course, many other contributions; the botanist, the physiologist, the zoologist, and others have all added their quota. —The Engineer, July 6, 1934.

STRENGTH OF MATERIALS.

This is a symposium on the practical applications of recent research into the strength of materials, based on the papers presented at a meeting of the Verein deutscher Ingenieure in November, 1933, in Essen. Only certain parts of this very interesting matter can be abstracted here.

CORROSION STRESS AS CAUSE OF RUPTURE.

Observations have shown that in the majority of cases a material decrease in long-range resistance to stresses occurs in connecting rods of double-acting two-stroke-cycle engines due to the effect of the cooling water. Extensive

tests have been undertaken by the M.A.N. Company to determine the properties of various materials of construction in this respect. All the samples were submitted to a maximum of 100,000,000 alternations of stress, as it was found that the limit of 10,000,000 alternations formerly used was not sufficient, and material continued to lose strength when tested after that limit. Tests were made with various corroding liquids from fresh water to sea water. The test pieces were flat bars subjected to from 3000 to 4000 alternations per minute on a M.A.N. bending oscillating machine. The results of these tests are given in the form of curves in the original article. Among other things it was found that corrosion was materially greater in the larger bores, that is, at lower velocity of flow of water, than in smaller bores and higher velocity of flow. In some connecting rods where a high water velocity was used, erosion was found, which, however, had no connection with corrosion cracks. Increase in temperature of cooling water produces materially greater corrosion. This was found in the case of a steel pipe where cold cooling water flowed on the inside while the outside was exposed to the action of the return flow of the warm cooling water. While the inner surface showed only slight indications of corrosion, the outer surface was quite strongly eaten away. This leads to a practical conclusion to the effect that the cold water should be made to flow through the drilled holes in connecting rods, while the warm cooling water should be returned through a pipe made of corrosion-resisting material. It is of particular importance to note that in the range of the largest heat stresses, no corrosion was observed. Contrary to the theoretical assumptions this zone is therefore least exposed to the danger of corrosion. Corrosion is assisted by guide strips inserted in the bore-holes. Cracks were frequently observed below and above these guide strips, but these cracks did not appear until after four to five years of operation.

As regards protection against corrosion, the most effective method is to insert into the bore-hole of the connecting rod a thin-walled tube made of a corrosion-resisting material. Protective mediums against corrosion when added to the cooling water have given very good results. Even a small addition of lubricating oil to cooling water produces a material improvement. In general, the effect of corrosion was materially greater in the case of soft water than in hard water, particularly with water containing common salt.

This report is a good example of the practical value of long-range testing. The observations made in the course of the tests show quite clearly that breaks in connecting rods are practically exclusively due to fatigue induced by corrosion and the elimination of troubles from this source can be achieved only by a fundamental study of corrosion fatigue as affecting the strength of materials.

COMPUTATION OF THE STRENGTH OF TURBINE BLADES.

The author, Dr. of Engrg. Mellan, considers separately the first and last rows of blades. The first rows are, of course, exposed to the high temperatures of the high-pressure steam. As the blades pass through the jets of steam coming from the nozzles they received periodic impulses, the frequency of which depends on the peripheral velocity, the number of blades, and the number of nozzles. This imposed frequency should not coincide with the natural frequency of vibrations of the blades, as otherwise resonance will be produced. This requirement is, as a rule, satisfied automatically as, for other reasons than that of the frequencies, the blades are short and very resistant against bending. The oscillating stresses induced by the impulses are therefore comparatively low. On the other hand the maintenance of strength requirements is made difficult by the use of high operating temperatures. The long-range strength of such materials as may be used for blades under high

temperatures has scarcely been investigated and experimental work in this direction is imperatively necessary. All that can be done today is to draw conclusions from tests on the strength of blades at room temperatures. Furthermore, in this connection the effect of corrosion due to the presence of salts in the steam and the effect of surface conditions, neither of which has been properly studied, must be considered. On the other hand, however, we know how to calculate reliably the tensile stresses induced by centrifugal forces and the bending alternating stresses induced by variations in steam pressure.

The last rows of blades are very long, but, on the other hand, the steam temperature is here only from 30 to 50 C. (86 to 122 F.) so that the difficulties due to high temperatures do not need to be considered here. The vibrations due to the impingement of steam from the nozzles also need not be considered here as the stationary guide blades are concentrically located about the rotors. The author considers in some detail, however, the creation of vibrations in the blades. In the last rows of blades the problem is to calculate the natural periods of vibration in the blades and to lay out the blades so that their natural periods of vibration should be from two to three times higher than the operating periods of vibration. The results of approximative processes for this kind of calculation, only very recently published, have been confirmed by practical experience.

LONG-RANGE RUPTURES IN MOVING PARTS OF HIGH-SPEED DIESEL ENGINES.

The author of this paper, Dr. of Engrg. E. Flatz, of Cologne, raises the question of the methods of calculating stresses in such machine parts as those entering into the construction of high-speed Diesel engines, and, in particular, the value of long-time tests. He says that results of recent research can be successfully used to create new machine parts and new shapes, and to meet new kinds of stresses, but calculation of actual stresses in motor parts is still quite difficult, as the shape of the part is not easily handled mathematically, and the forces occurring in practical operation can be given only in a very approximate manner, with the result that the results obtained may vary as high as 100 per cent. Moreover, the calculation of stresses requires so much previous experience that it can be made successfully only by highly trained engineers.

In computing standard machine parts differing only slightly from those commonly used the Humboldt-Deutz Motors Co. uses certain simple models. In large organizations this makes it possible to proportion more uniformly more or less similar machine parts. It must be remembered, however, that, while the value of permissible strains assumed in model tests has the dimension of the stress, it does not by any means represent the actual strain. When, however, proper precautions have been taken the method of determining stresses by means of models cannot be said to be opposed to the spirit of the modern science of strength of materials.

The design of a part of a motor as a body of a strength equivalent to that of a model is, however, time consuming and greatly limited by practical considerations, particularly those relative to the methods of manufacture. Research in materials has hitherto been content, particularly in long-range tests with machined pieces or models, to find ways of eliminating troubles after they have occurred. Experience shows that ruptures in motor parts are practically exclusively due to peak stresses produced by disturbances in the "flow of power." For practical purposes, it would appear to be particularly necessary to develop a theory of peak loads that would hang together well. As regards research generally Doctor Flatz makes the following statement: "Even the results of research that we have available today are of inestimable value. While precise computation of strains in motor parts has not been very

well developed as yet and has not been carried out far enough so that it could be applied to shapes of machine parts very different from those now used, the economical value of such knowledge as we have on the subject of peak strains is tremendous. Without exaggeration one can say that by this research millions of marks have been saved in the German economic system."

CRANKSHAFTS.

In Figure 1 are plotted for a number of crankshafts of small single-cylinder Diesel engines curves of nominal stresses obtained in accordance with the usual formula for strength of materials for cross-sections *a* and *b*, assuming a bending stress due to the maximum pressure on the piston.

Figure 1 is based on analytically determined bending strains ("nominal stresses"), *a* in the crankshaft pins and *b* in the crankshaft cheeks.

The broken lines apply to strains in crankshafts of the third group, after reinforcement. No fractures were here observed. The first two ordinates apply to carburetion motors and the next three to Diesel motors. The bending moments were determined exclusively from the ignition pressure on the piston (50 atm gage for Diesel motors and 20 atm for carburetion motors) and distance between bearings, without giving any consideration to forces of acceleration. This has been done, as only comparative figures for motors of the same kind were desired. The various figures apply to German standard steels. ME2Wv is a manganese steel.

The results of a large-scale investigation of breakages in crankshafts from among 150,000 motors now in operation shows that when the crankshafts have been built out of the German standard steel St 50.11, breakage occurred when the "nominal stress" at *b* was higher than about 7 kilograms per square millimeter (9954 pounds per square inch) or corresponds to a strain of about 11 kilograms per square millimeter (15,642 pounds per square inch) at *a*. As the alternating bending strength of this steel is about ± 25 kilograms per square millimeter (35,550 pounds per square inch), it would appear that the actual strain at *b* is about 3.5 times as great as the nominal strain.

From the statistical analysis of breakages, proper indicative values for the selection of permissible nominal stresses to be used in the design of this kind of shaft have been obtained.

CONNECTING-ROD BOLTS.

This machine part requires the most earnest consideration, as its failure in the majority of cases results in a complete destruction of the machine. The fracture practically always occurs in the first stressed thread turn. The following have been found to be its causes: (*a*) Failure of material, particularly porosity due to improper heat treatment; (*b*) improperly cut thread, loosening, or crooked seating of the nut. The following are recommended as means to prevent such failure: (1) Employment of materials not too sensitive to heat treatment; (2) the most careful machining of the thread, which should be milled and strengthened by surface pressure treatment; (3) the most careful machining of the nut, with the bearing surface precisely normal to the axis of the screw; (4) provision of the right amount of stressing in erecting and protecting the nut against loosening.

Connecting-rod bolts have hitherto been computed chiefly in respect to tensile strength. As a basis for the calculation there were used the mass forces resulting from the motions of the piston and connecting rod and occurring in a four-stroke-cycle Diesel engine only at the end of the exhaust stroke and in two-stroke-cycle engines only when the compression failed. Even if, for purposes of this kind of calculation, a nominal strain was assumed thirty

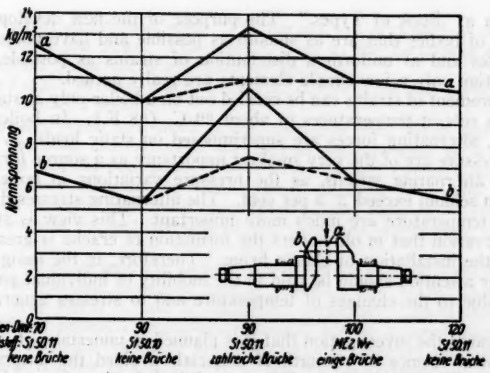

FIG. 1. EVALUATION OF OBSERVATIONS ON 150,000 CRANKSHAFTS OF SMALL MOTORS BUILT BY THE HUMBOLDT-DEUTZ MOTOR CO.

(*Nennspannung* = "nominal stresses"; *kolben-Dmr*:70 = diameter of piston in millimeters; *werkstoff* = material; *keine Brüche* = no cases of breakage; *zahlreiche Brüche* = numerous cases of breakage; *einige Brüche* = some cases of breakage.)

times the elastic limit, cases of fracture could not be avoided. In the Humboldt-Deutz Motor Co. the bolts are now so computed that they are given a sufficient initial stress to take care of the friction between the two halves of the connecting-rod head, bearing in mind the acceleration of a cross-section of the rod. The fundamental features of this calculation do not depend on the way the motor works. If we consider that the peak loads occur at the base of the thread, it will be found that if the dimensions have been determined from the erecting stress alone there will be at most a factor of safety of two. Experience has shown that where closure by friction is lacking, particularly when, because of the rotary oscillations of the crankshaft, very large accelerations of cross-section appear, the screws fail. The correctness of the present method of computation has been confirmed by measuring the erection stresses, these measurements having been carried out by calibrating the terminal surfaces of the screw and determining the total elongation of the screw as a measure of the strain.

MATERIAL FOR STEAM BOILERS.

The paper by Dr. of Engrg. E. Lupberger deals with the selection of material and wall thickness in steam boilers. Here again the opinion is expressed that the empirical methods now used cannot endure. But in order to replace them by really scientific methods one must above all know the special field of stresses at the critical locations in the boiler. They cannot be determined for practical purposes by mathematical methods. The solution of the problem can rather be found only by experiment. It is therefore the intention within a very short time to submit to elongation measurements the few typical parts which alone are of importance for the design of new boilers, and to determine in this way the distribution of stresses. These experiments are to be carried out as a community undertaking and the results are to be pre-

sented in a "Book of Types." The purpose of the new development is the creation of bodies that are as smooth as possible and have undisturbed flow of stresses and as uniform a distribution of strains as possible. In boiler construction only a few simple elements are really needed.

Measurement of strains can be carried out on a boiler only at static pressure and as a rule at temperatures of about 20 C. (68 F.). In boiler operation, however, alternating forces are superimposed on static loads. Variations of steam pressure are of the very smallest importance as a source for the appearance of alternating strains, as the pressure variations in boilers while in operation seldom exceed ± 5 per cent. The alternating stresses due to variations of temperature are much more important. This view is supported by the observation that in old boilers the formation of cracks is greatly accelerated by the installation of elastic firing. Therefore, in the design of boilers particular attention should be paid to the mobility of individual parts, such as may be due to the changes of temperature and to stresses generated in that way.

As regards the investigation that it is planned to undertake, it is stated that the classical science of strength of materials avoided the uncertainty as to the relation between simple tensile tests and the behavior of materials observed in practical operations, and it did it by the introduction of an "experience" or safety factor. All efforts of modern research in the field of strength of materials, testing of materials, and analysis of parts has not been able to eliminate completely this safety factor. This could be done only by making calculable in advance all the influences which necessitate its use.

The following of these influences are named here: (1) The difference between the behavior of material in a tensile test and its behavior under a special state of strain in a boiler. (2) Deviation of the properties of material as represented by a test bar from the properties in an actual construction which includes defects in manufacture, porosity, non-uniform heat treatment, etc. (3) Lack of precision in the computation of the strains occurring. (4) Differences between the properties of the material which are assumed in the computation of parts and the properties of the material when it undergoes actual strains. (For example, in test computations when dealing with the tensile strength and the elastic limit of materials, while in long-range straining the corrosion effect has to be considered.) (5) Reduction of the resistance of material during operation because of corrosion, changes in the condition of surface, etc. (Symposium in *Zeitschrift des Vereines deutscher Ingenieure*, vol. 78, no. 13, Mar. 31, 1934, pp. 395-401, illustrated. The last article of the symposium, "Numerical Calculation of Long-Range Failures in Operation," has not been abstracted because of lack of space. *etA.*)—"Mechanical Engineering," July, 1934.

THE GREAT GUN PROBLEM.

A daily paper has recently told the world that the official organ of the German Admiralty has published particulars of a naval anti-aircraft gun which hitherto has been completely hush-hush in this country. It has been in fact what the late W. E. de B. Whittaker used to call "a secret known to everybody but ourselves." This wonderful weapon, which is commonly known as the multiple pom-pom, is described thus in a translation from the German paper:

"In the development of anti-aircraft machine-guns the British are foremost with the 4-centimeter (1.17-inch) eight-barreled, power-worked mounting. The ammunition feed is by means of belts of fifty rounds each, and the

gun is served by about nine men. The barrels are arranged in two series, one series above the other. The fuses are set as the cartridges are fed to the breech, and tracer shells are used for spotting.

"With all eight barrels in action the rate of fire from this multiple gun is 800 to 1000 rounds a minute."

Which means, when you work it out, that nine men serve eight barrels, instead of one man one barrel in the normal machine-gun, or a couple of men to run a normal pom-pom. The number needed to carry ammunition would be in proportion to the rounds fired—whether from one gun with eight barrels or eight guns with one barrel. Eight belts of 50 rounds each means 400 rounds, so each loading of this pom-pom would only last half a minute.

Naturally, all of us who are closely in touch with aviation have been talking about the multiple pom-pom among ourselves for years. And nobody except the navy seems to take it frightfully seriously. Low-flying torpedo-planes attacking behind a smoke-screen would not be in much more danger against such weapons than they would be against ordinary pom-poms, or a corresponding number of quick-firers of the Vickers-Armstrong type which was described and illustrated in "The Aeroplane" of October 11, 1933. That is the type which is now being fitted to some of our heavier flying-boats.

In fact, a large number of such quick-firers ranged along the gunwale of a ship would probably set up a more effective barrage than would the same number of barrels packed into a smaller number of these multiple pom-poms.

Against high-flying bombers, which seem to be the most effective weapons of all against warships, this type of pom-pom would be less effective than the normal 3-inch anti-aircraft gun, which in the early days of the War 1914-18 was nicknamed "Archie" by a certain Captain Borton, R.F.C., now Air Vice-Marshal.

Against dive-bombing, for which there seems to be a craze here and in America, the multiple pom-pom might be effective if the authorities persist in using the present tactical methods, by which the machines dive out of formation one after the other in a long string. Such a method would allow the pom-pom crews to set up a screen of fire through which the aeroplanes would have to dive, and somebody would certainly be hit—something on the lines of the remark of the gamekeeper, who, when a city sportsman blazed into the brown of a bunch of driven grouse and hit one, said, "They *will* fly into it sometimes, sir!"

The multiple pom-pom, for all its secrecy, seems to be nothing much more than a development of the multiple machine-gun which was invented and built by Mr. Pemberton Billing when he was in the Royal Naval Air Service in the latter part of 1914. In those days aeroplanes flew low and could be reached by machine-guns which carried up to about 8000 feet.

Pemberton-Billing arranged twelve Lewis guns in a circle round a vertical mounting, which could be swung round much like the nozzle of a hose inside quite a large section of a hemisphere. The guns were fired by Bowden wires attached to the triggers and all operated by one handle.

The barrels were attached to the central mounting by springs, so that the first shots went up parallel to one another and then the recoil pulled the guns out against the springs in such a way that the muzzles moved outwards, rather like the ribs of an umbrella when one begins to open it. Thus the bullets sprayed out like a fountain.

The idea was quite sound, and if it had been applied to pom-poms of the type which was evolved during the South African war, quite a useful anti-aircraft weapon might have been evolved.

From the point of view of Air Force attack the multiple pom-pom is rather to be commended, because, if one gun is hit in a converging bombing attack, eight barrels are put out of action—and there would be considerably more difficulty in putting eight separate guns out of action.

Another advantage from the Air Force point of view is that these guns will get rid of such vast quantities of ammunition that supplies will be exhausted quite quickly, unless a warship is going to carry so much ammunition that it is on the verge of sinking when leaving port.

On the whole, the multiple pom-pom is not an impressive weapon, and we should not be at all surprised to learn that the Admiralty has deliberately released this popular secret simply to persuade our possible enemies overseas that the navy still lives in the state of placid self-satisfaction which was its chief characteristic up to 1919.—"The Aeroplane," June 13, 1934.

SOARING PLANES.

Some Practical Considerations in the Design of Engineless Airplanes.

By Ralph S. Barnaby.*

This paper was prepared with two purposes in view: (1) To acquaint aeronautical engineers and designers with the problems of soaring-plane design in the hope that more of the talent that goes into airplanes in this country may be directed toward this interesting phase of aviation, and (2) to stimulate discussion among glider designers.

Soaring is sustained flight without power. It is accomplished by gliding in rising air currents whose vertical velocity is equal to or greater than the sinking velocity of the glider. These rising currents are either thermal or the result of a wind blowing against an obstruction, such as a ridge, and flowing up and over it like an inverted water fall.

SELECTION OF AIRFOIL FOR SOARING PLANES.

One of the first requirements of a soaring plane must be a sinking velocity sufficiently low to take advantage of these ascending currents. Again, in order to be able to fly in relatively high winds, to enable it to get from one favorable spot to the next, and to pass through down-current zones as rapidly as possible, a high flying speed is desirable. These two requirements combine to make the requirement of a flat gliding angle.

The selection of the airfoil for use on the glider is a matter of utmost importance.

A simple sketch will make this evident. (Figure 1.) Assume two gliders of the same minimum sinking velocity, one having this sinking velocity at an overall L/D (ratio of horizontal to vertical distances) of 10 and the other at an L/D of 20. Both will maintain altitude with the same minimum ascending current velocity, but the one with the flat glide angle will have a normal speed of twice that of the other. Because of this it can go through zones of low ascending or descending currents with less loss of altitude because it will be exposed to them for a shorter time. It can fly in higher winds and make headway to windward. For cross-country soaring these features are essential.

* Lieut-Comdr., Construction Corps, U. S. Navy.

Presented at a meeting of the Metropolitan Section, New York, N. Y., November 28, 1933, of The American Society of Mechanical Engineers. Abridged.

FIG. 1

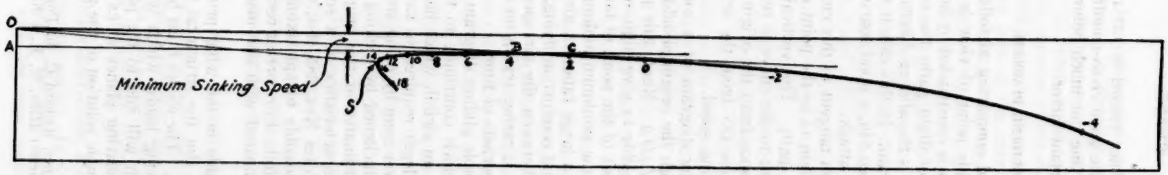

FIG. 2

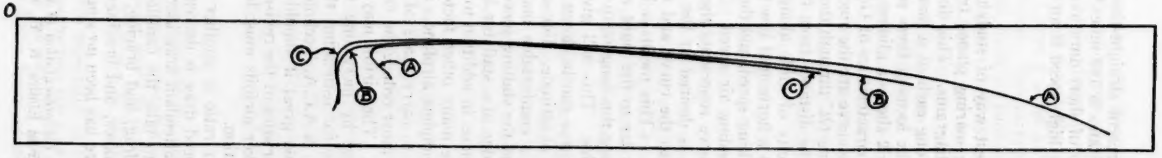

FIG. 3

The present straight-line distance record is 137 miles; the record in the United States is 122 miles.* Since good cross-country soaring conditions are generally of short duration, starting not much before noon and ending with darkness, high speed is an important factor.

THE GLIDING DIAGRAM.

The best way of studying and comparing airfoils, wing combinations, or complete soaring planes from this point of view is by comparison of their gliding diagrams. This diagram is constructed by laying off from a common origin along each of a number of flight paths the velocity of glide for each path. The locus of these points is the gliding diagram.

Figure 2 shows a gliding diagram. In this case it was constructed from the airfoil characteristics of Göttingen 549, a good soaring airfoil. The numbers along the curve are the angles of attack.

The line OC through the origin tangent to this curve is the flattest gliding path. The distance from the origin O to the point of tangency C represents the velocity of glide along this path. The vertical distance OA from the origin to a horizontal line tangent to the curve is representative of the minimum sinking speed, and the distance from the origin to this point, OB, is the corresponding air speed. The line OS from the origin to the nearest point of the curve represents the stalling speed.

What is desired in the gliding diagram of a soaring plane? First, the tangent to the curve and through the origin should have as flat a slope as possible. (This means a high L/D.) Next, this point of tangency should occur as far to the right as possible to give high speed. Finally, the curve should hug this tangent to the left of the point of tangency to as low a speed as possible. This will give a low minimum sinking speed. A glider with such a curve can be flown over a large range of air speeds with a minimum sacrifice of altitude. For ease and comfort in flying, however, it will be well to have a comfortable margin between the air speed for minimum sinking speed and the stalling speed. It is rather trying on the nerves to be hanging on the edge of a stall for long periods of time.

Of course, in addition to a simple gliding diagram from simple airfoil data, there are many other factors which contribute to the final gliding diagram of the complete airplane. First, an airfoil, which has a fine diagram, may be too thin to carry spars of the depth required to carry the load. In such a case we must reduce the cantilever span by using struts, or thicken the wing, or both. The airfoil may be thickened by picking some other and thicker section or by increasing the ordinates of the original section. A method and data for estimating the characteristics of a section so "fattened" are given in N.A.C.A. Technical Notes Nos. 385, 391, and 404. If the increase is not too great it should be possible to approximate fairly accurately the characteristics of the revised airfoil. For correct results, gliding diagrams for the thicker airfoils must be compared with one made up for the wing-strut combination.

Aspect ratio is another variable in the wing problem. If it is increased the induced drag is decreased. But the structural problems become greater and the attendant drag increases. The choice must be made between a thicker airfoil, to take the cantilever wing loads, which will probably increase the profile drag, and bracing, which will add to the parasite drag. The many sizes, shapes, and bracings of soaring planes in existence attest to the fact that there has been no single simple solution of the problem to date.

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* Since the presentation of this paper, Richard C. du Pont, on June 25, 1934, piloted a glider from Elmira, N. Y., to Somerset Hills, N. J., a distance of 155 miles.—Editor.

Gliding diagrams can be compared to determine the best combination of aspect ratio and wing section. In Figure 3 the gliding diagrams of three wing arrangements have been superimposed. Curve *A* is the diagram of a strut-braced wing, aspect ratio 15, based on the Göttingen 549 airfoil, the maximum thickness of which is 13.85 per cent of the chord. Curve *B* is for a cantilever wing, aspect ratio 15, based on the Göttingen 535 airfoil. This airfoil, because the thickness is 16.05 per cent of the chord, lends itself to cantilever construction. Curve *C* represents a strut-braced wing, aspect ratio 20, also based on the Göttingen 535 airfoil. From a comparison of these curves it appears that wing *A* has the flattest gliding angle and that it occurs at a considerably higher speed. Wing *C* has a slightly flatter gliding angle than *B*, and at a considerably higher speed. Wing *C* has the lowest sinking speed. It occurs, however, much nearer the stalling speed than in the cases of *A* and *B*. Wings *B* and *C* both have slower stalling speeds than wing *A*. As the speed increases the sinking speeds of both *B* and *C* increase at a faster rate than does that of *A*. In general it appears that wing *A* maintains an average of lower sinking speeds over a greater range of flying speeds than do either of the other curves. It would be the best wing, therefore, for all-around use.

Since increase in aspect ratio and properly tapering and shaping the wing tips in plan form reduce the induced drag, these refinements are necessary if high performance is to be obtained. Just how far to carry aspect ratio is debatable. While a number of the German soaring planes have gone higher, it seems as if there were little practical gain in going beyond an aspect ratio of 20. As the aspect ratio increases, so do the structural problems. The problem of taking care of torsion in a wing of high aspect ratio, especially if the glider is going to be subjected to the higher speeds involved in airplane towing, becomes serious. I believe that a successful all-around soaring plane need not have an aspect ratio of more than 15.

While it is well known that for the utmost performance all the aerodynamic refinements known should be used, I believe that more can be learned in the long run if some of them are sacrificed to produce a rugged plane capable of moderately high performance, or that will stand rough service and towing, that will cost less, and that can be flown more frequently than can the extreme types.

REQUIREMENTS FOR A "UTILITY" SOARING PLANE.

Let us consider some practical requirements for what might be called a "superutility" or "utility" soaring plane.

It is frequently necessary to resort to airplane towing in order to reach altitudes where thermal and storm-front soaring become possible. This means that the soaring plane must be designed for gust-load conditions at airplane-towing speeds, with a liberal factor of safety. Under such conditions the torsional strength and rigidity of the wings become important factors because of the extremely low angle of attack necessitated by the excess flying speed.

WING CONSTRUCTION.

Both strut-braced and full-cantilever wings are used in soaring planes. It appears that many practical, structural, and maintenance advantages may be gained from the use of strut bracing without sacrificing much in performance. Kronfeld's "Wien" is an outstanding example of what can be accomplished with strut-braced wings.

Probably the stiffest wing construction, for torsion especially, is that used for most of the German soaring planes. In this construction the spar, usually a box beam, is set well back in the deep section of the airfoil. The leading edge is of plywood and with the spar forms a tubular beam of elongated

D-section. The monospar type of beam construction might be feasible, but when it is considered that it is necessary to cover the leading edge of the wing with some stiff material in order to maintain the correct airfoil section, it would appear that the advantage is with the D-spar, which puts this leading-edge fairing to work. It is obvious that with the large cantilever overhang and tapering plan form, the conventional two-spar, single-drag truss wing is quite unsuited because of its lack of adequate torsional strength and rigidity.

FUSELAGE, LANDING WHEELS, AND COCKPIT.

Probably the most important consideration with respect to the fuselage is to provide a side profile with sufficient rise to the tail to permit the attainment of high angles of attack on the ground, both for take-off and landing. The crash of a two-seater soaring plane at Elmira last summer was chiefly due to the small permissible ground angle which prevented the plane from getting into the air. In automobile-towed launchings, the ability to use a high-angle take-off cuts down the ground run appreciably. Again, if we intend doing extensive cross-country flying, which after all is the supreme sport of soaring, it is practically necessary that we have a glider that can be set down in a small space at a low speed.

While plywood monocoque fuselages of oval cross-section undoubtedly have the lowest drag, I believe that first cost, ease of inspection and maintenance, and length of life dictate a fabric-covered, tube-frame fuselage, suitably faired by false-work and fairing strips. Considerable wear and tear can be avoided if the bottom of the fuselage is covered with a light duck rather than the usual covering fabric.

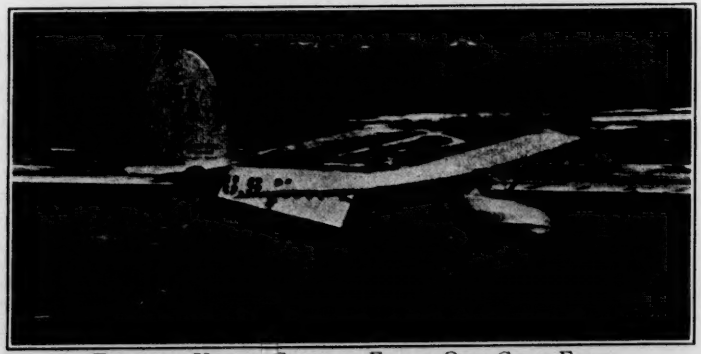
If the soaring plane is to be used only in shock-cord launchings from grass-covered take-off sites, a skid is sufficient and the weight, drag, and complication of the wheel installation can be dispensed with, but such a glider will have a very limited use and will hardly fall into the class of the practical utility soaring plane.

The use of landing wheels on gliders and soaring planes is a distinctly American innovation. It is undoubtedly a by-product of automobile and airplane towing. The relatively slow acceleration and resultant longer take-off run imparted by these towing means as compared with the shock-cord launching make the use of the skid impracticable. One day of average operation of a skid-equipped glider, auto-towed from the average airport, will wear out a wood skid. In addition, the convenience of the wheel in ground-handling puts the wheel landing gear in the class of practical necessities.

A single wheel is undoubtedly the most satisfactory from all points of view. It is light, has a low drag, and lends itself readily to a simple brake installation. Maneuvering on the ground with a single wheel is readily accomplished in a manner only possible with a two-wheel landing gear equipped with pedal-operated brakes, a complicated installation, at best.

For maximum maneuverability and control on the ground, the wheel should be located approximately under the center of gravity when the glider is in flying attitude. This, of course, requires the use of a skid, ahead of the wheel, which can be put in contact with the ground by raising the tail about 10 degrees by the application of the brake or by pushing the stick forward. While it would be possible to set the wheel ahead of the center of gravity as is customary in airplane design, it would seriously impair taxiing and maneuvering on the ground, and would give no particular advantage. The angle between the normal-flight-path attitude and the tail-down attitude should be at least 15 degrees.

Too much attention cannot be given to the arrangement of the cockpit and the installation of the necessary equipment. A comfortable well-arranged



FRANKLIN UTILITY GLIDER IN FLIGHT OVER CORRY FIELD, NAVAL AIR STATION, PENSACOLA, FLA.

RICHARD C. DU PONT AT THE END OF HIS 155-MILE FLIGHT IN A MOTORLESS PLANE, JUNE 25, 1934.

cockpit with properly installed instruments may be as important a factor in successful soaring as proper aerodynamic and structural design. For drag reduction and also in the interest of increased comfort a suitable cockpit enclosure should be provided. Its attachment should be such that it may be readily installed and removed. It must be held securely in place so that violent bumps will not dislodge it, but, on the other hand, one good shove should suffice to remove it in event it should ever become necessary to "bail out."

CONTROLS.

The shape of the fuselage will have considerable effect on the type of controls to be used. The slender lines of the nose of the soaring plane practically require the use of rudder pedals rather than a bar, so that the feet may be kept close together. This same slenderness, further aft, interferes with lateral stick movement. In laying out the seat and controls the designer should bear in mind that flights of 6, 10, 20, perhaps more, hours will probably be made, and that since the pilot, because of the limited space, will be unable to shift his position much, the arrangements should be as easy and comfortable as possible.

In the design of the controls, every effort should be made to reduce friction and lost motion. In soaring, particularly, it is important that the pilot be able to feel the air forces on his controls. I know of few things more uncomfortable than flying a glider with controls aerodynamically sensitive and mechanically stiff. It is a practical impossibility to get the best performance out of a soaring plane in this condition.

Aside from the air controls, there should be conveniently located and so placed as not to be confused, the tow-line release, the brake control, and the tail release, if any.

A soaring plane to be universally useful must be capable of being towed by an airplane. This means that provision must be made for the installation of a parachute, which the Department of Commerce requires for such flights.

LAUNCHING MECHANISMS.

After watching many shock-cord launchings, I am convinced that some positive means should be provided for releasing the glider for take-off. The usual method, in which men hang on to ropes attached to the tail, is hazardous for men and equipment. Some soaring planes are equipped with pilot-controlled trip hooks in the tail, similar to the towing hook used in the nose when the plane is launched by towing. This seems to me to be an unnecessary complication. My suggestion as the simplest and most foolproof method is to use what might be called a mechanical fuse, *i.e.*, a tail attachment which includes a readily replaceable calibrated "weak-link" member, designed to break at the desired load. For instance, one simple device would be a shackle or clevis on the end of the hold-back line which would be held to a lug in the tail of the glider by means of a shear pin. Using copper, brass, and iron nails, and various tempers of copper, aluminum, and iron wire of standard diameters, suitable shear pins could be found that would take care of any desired release tension. Probably the best and certainly the most mobile anchor for the hold-back is the wheel or bumper of an automobile parked at right angles to the take-off direction.

EASE OF ASSEMBLY.

Next in importance to strength and aerodynamic qualities comes mobility. In order to get the most use out of a soaring plane it is necessary that it be on the starting site ready to take off at the proper time. If a flight terminates

somewhere away from the starting point, it must be possible to get it back ready to start again in the shortest possible time.

In designing the assembly features of a soaring plane, it should be borne in mind at all times that it may be necessary to assemble and dismantle it many times in a day. Alignment should be automatic. Bolts and pins should be neat, but the fit should not be too tight. The nuts on bolts should be free running so that they may be readily run on by hand and tightened, where necessary, with a minimum amount of wrench use. Spring-wire safety pins are almost universally used for cotters for nuts and clevis pins. Push-pull rod controls are advisable from the assembly point of view. They halve the number of connections to be made and broken, and require no adjustment. It should be possible for three men to remove the plane from the trailer and set it up ready to fly in 15 minutes.

A two-piece wing is preferable to a three-piece wing. It is both lighter and more readily assembled. In some of the soaring planes of extremely large span the three-piece construction has been necessary because of handling and trailer difficulties. In the utility soarer the span will not be great enough to present these difficulties.

INSTRUMENTS REQUIRED.

Of the instruments required, probably the most important is the barograph, yet to date few gliders have provided a suitable place for installing one. A barograph must be carried on every important flight and in any contest flight. It is installed just before and removed just after each flight. Much valuable time will be wasted if an accessible barograph compartment is not provided.

A soaring plane should be provided with a rate-of-climb indicator, an altimeter (preferably of the sensitive type), and an air-speed indicator. If one of the new-type sensitive altimeters is used, *i.e.*, one in which the "minute" hand makes one revolution per thousand feet and the "hour" hand one every ten thousand, it will be necessary to provide some sort of vibrator for it, such as an electric buzzer or a reed sticking out into the air stream, otherwise the friction of the gear train produces so much lag as to render the instrument useless. (In an airplane the engine provides the necessary vibration.) If so equipped, however, the sensitive altimeter becomes a most important instrument, rating close behind the rate-of-climb indicator. If extended flights and cloud flights are to be made, a compass and a turn-and-bank indicator are necessary. One of the most important instruments is a watch, but the author is assuming that it will be carried on the pilot's wrist.

If long soaring flights are to be made it may be necessary to continue after nightfall, in which case running lights are necessary. Provision for the necessary lights in accordance with the Department of Commerce regulations should be made.

TRAILER DESIGN.

After attending four national soaring contests and taking part in several independent soaring expeditions, I have developed some fairly strong ideas on trailer design. For instance, after having seen wing struts ruined by being run over by an automobile while laid out on the ground preparatory to assembly, I believe that the trailer should be designed so that parts may be removed from it for assembly in the order required and replaced on the trailer in the order they are dismantled. A trailer which requires that the wings be removed and laid on the ground in order to get out the fuselage is a distinct hazard.

Some of the roads leading to soaring sites are fairly steep. The lighter the trailer, the sooner the site will be reached and the longer the tow car will

last. However, in striving for lightness there are certain features which should not be impaired or jettisoned. First of all, the trailer must be rugged enough to withstand distortion which might put dangerous stresses on the glider parts. It should protect the glider from the elements. It should be provided with adequate and convenient stowage space for tools, parts, and repair material. A small shelf with a vise is very handy. A substantial towing attachment is essential. The trailer wheels should be so located that there will be a moderate down-load on the towing attachment when the trailer is loaded. Wiring for a trailer tail light should be provided.—"Mechanical Engineering," August, 1934.

MECHANICAL HANDLING OF AIRSHIPS.

D. M. Mackey, Lieutenant, United States Navy.

The arrangements for handling the U. S. S. *Macon* at the Naval Air Station, Sunnyvale, Mountain View, California, represent the result of over six years' experimentation on the part of the Navy in the mechanical ground handling of rigid airships. Military necessity for docking and undocking ships of increasing volume in more than moderate cross-hangar winds has made this development mandatory. Mechanical handling means a small ground handling crew, as well, which is a necessity if airships are to be used commercially.

The German Government felt that mechanical handling of airships was impractical and refused to grant patents for ideas of this nature. As a result the Germans were never encouraged to develop this phase of airship operation. During the World War they built revolving hangars which could be trained into the wind and these were used quite successfully with their small ships. It is only within the last year or so that the *Graf Zeppelin* has been docked at Friedrichshafen with the aid of mechanical gear. This has undoubtedly been stimulated by the building of the *LZ-129* which will be about the size of the *Macon*.

Our original arrangements for handling the airship on the ground consisted of a system of bridles secured to trolleys running in slotted tracks, which held the bow and stern of the ship while it was being walked in and out of the hangar. The stern was supported on a large pneumatic taxi-wheel, while the control car was supported on a small flat car running on railroad tracks. When the ship had been moved out of the hangar, it was disconnected from the bridles, allowed to swing into the wind and then walked across the field and secured to the high mast. While riding at the high mast the stern was held to the ground by a tail drag which compensated only for minor oscillations of the stern. It was necessary to have a flight crew aboard and practically fly the ship at all times.

The development of the stub-type of mooring mast resulted from a desire to get away from the use of the high mast. It was felt that if the stern could be secured to a car on the ground which was free to swing with changes of wind the ship would be much more secure and riding out would be less of a strain on the crew. At first, it was not considered practical actually to land the ship at this stub mast. Instead, it was landed on the ground, following the German practice, and then walked over and secured to the mast. It was found that the ship rode to this mast very well. Encouraged by this it was decided to attempt a mooring directly to the stub mast. This also proved entirely feasible. The idea of the mobile stub mast was then considered and specifications were prepared in 1926. It was not until the latter part of 1928 that this first mobile mast was completed.

The first mobile stub mast was triangular and was similar in appearance to the present mast. It was supported by three caterpillar treads and was

towed by a powerful tractor. The winches for hauling the ship down were located at the center of the mooring circle, to which the mast was towed after the ship was undocked. This system of handling the airship proved quite successful and the *Los Angeles* was moored, docked, and undocked by means of the mobile stub mast until her decommissioning in 1932. At times it proved troublesome because the weight of the mast was too great for the treads, causing frequent breakage of links and other parts. Again, the stern handling arrangement could not be connected unless the ship could be hauled up to within about 30 degrees of the hangar axis.

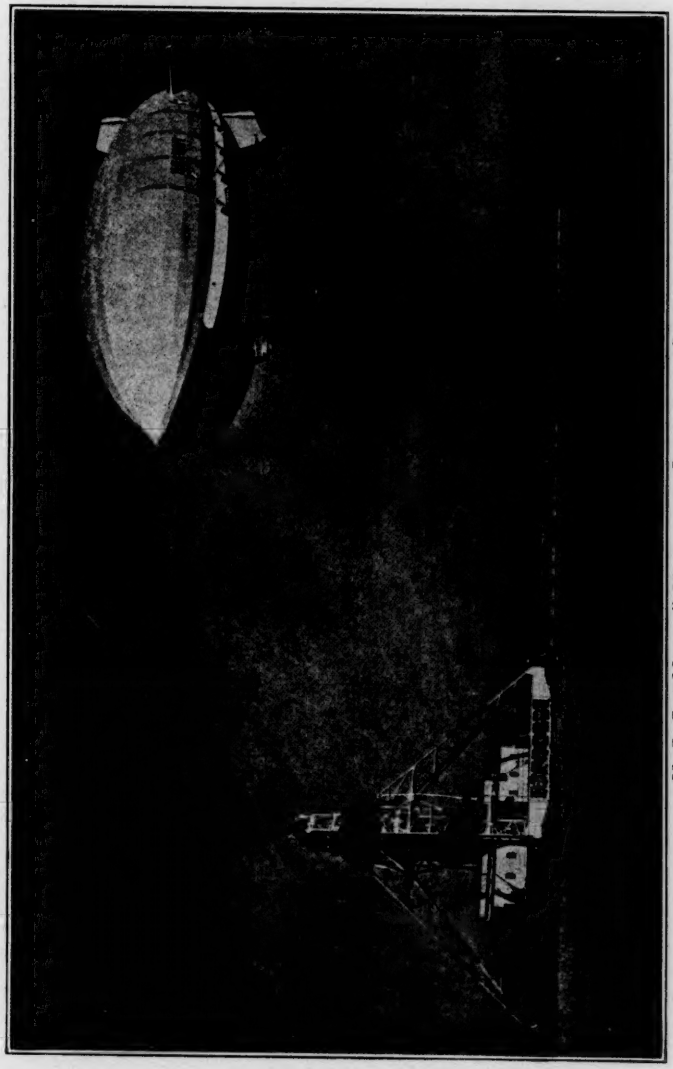
In order to accommodate the *Akron* and the *Macon* a new mast was designed to run on railroad tracks and to be towed by an electric locomotive. To hold the stern of the ship the stern beam was designed which would run on straight tracks in and out of the hangar and then could be shifted to a circular track without disconnecting the holding bridles. The beam would then be free to move around the circular track until the ship was into the wind. Certain undesirable features of this equipment were imposed by the layout of the hangar and field at Lakehurst. These were eliminated in planning the hangar and field at Sunnyvale. From the experience gained in operating this equipment at Lakehurst with the *Akron* the present equipment was designed.

The principal items consist of a telescopic mobile mooring mast; a mobile stern beam for hauling the stern of the airship up against the wind and for holding it rigidly during the period of travel into or out of the hangar; spreader gear for forming a rigid connection between the mast and the stern beam during the period of travel; a riding out car to support the stern when the ship is moored outside the hangar and to permit it to swing freely with the wind; two so-called yaw guy cars which act as anchor points for the guys running from the bow of the airship to the ground during the preliminary stage of mooring.

Two sets of standard gage railroad tracks, 80 feet apart run through the hangar to points 1500 feet north and south of the hangar. At the ends of these tracks are two circular tracks of a radius 643 feet, designated as the north and south mooring and hauling-up circles. The whole system of trackage is practically level, there being a maximum up grade on the straight tracks of 1 per cent. At the center of each circle are located water and fuel tanks as well as connections for helium supply, electric power, and telephone.

The mobile mast, built by the Wellman Engineering Company, of Cleveland, Ohio, to Navy specifications, consists of a pyramidal structure riding on four trucks 80 feet between center lines. On the main platform at the base of the mast are located the power house, the hoist house, and two 1000-gallon water tanks. At a point of vantage above the tops of the machinery houses is located the operators' cab. The mast is provided with an extensible portion composed of two vertically hoisted sections. The top section telescopes into the lower one and the latter into the central opening of the main structure. The lower section of the mast is raised and lowered by a cable system operated by the mast hoist mechanism, which is located in the machinery house. The upper sections, supported by a system of cables, is automatically raised or lowered by the corresponding vertical movement of the lower section, the entire system causing a simultaneous travel of the two sections. The minimum height to the centerline of the ship is 75 feet, while the maximum in the extended position is 160 feet. Wheel loads are about 30,000 to 35,000 pounds.

The source of power for the various functions of the mast is an 8-cylinder, Viking II engine delivering 565 horsepower at 1200 R.P.M., which drives a 250-Kw. generator with a 25-Kw. exciter on the same shaft. Travel of the mast is provided by four mine locomotive shunt motors, one located on each of the four trucks. Each motor develops about 7500 pounds tractive effort.



U. S. S. "Macon" Mooring at Sunnyvale, Calif.

The speed of travel is about 1½ miles per hour. In the hoist house are located the hoist gear for raising or lowering the mast and the main mooring winch for hauling the ship down. Other items of equipment on the mast consist of an air compressor and reservoir for the air brakes and a booster pump for delivering ballast water up the mast to the ship.

The stern beam, also built by the Wellman Engineering Company, is a massive structure 183 feet long and weighing about 300 tons. It can travel on either the straight hangar tracks or the circular tracks at the mooring circles. A jacking mechanism provides for the transfer from the straight to the circular tracks. Along the top of the beam is a track conforming to the curvature of the mooring circle on which travels the carriage which supports the lower fin of the airship. At the ends of the beam are side anchor cars which carry a system of bridles extending to the main structure of the airship and which, when run out to the limit of their travel, place the proper tension in the bridles for holding the stern of the airship rigidly centered on the beam.

The beam is powered by an 8-cylinder gasoline engine developing 240 horsepower. A main and auxiliary generator with a common shaft are driven by the gasoline engine. The main generator has a rating of 160 Kw. and supplies power for the circular-truck motors alone. The auxiliary generator of 35 Kw. supplies power to all motors except the circular trucks. In addition it furnishes excitation to the fields of the main generator and the four circular-truck motors. These latter motors develop a draw bar pull of 50,000 pounds, and the speed is from creeping speed to 10 miles per hour. The straight-track trucks are equipped with small motors which provide for moving the empty beam along the straight or hangar tracks, but these can be thrown out of gear by clutches when the beam, as a trailer, is moved by the mooring mast.

The spreader gear consists of two long pipes mounted on light trucks which travel on the straight tracks and act as a rigid connection between the mast and the beam while the ship is being towed in or out of the hangar. The riding out car is a small light flat car which runs on the circle and supports the fin of the airship. It is of the same height as the top of the beam and can be coupled thereto during the process of transferring the fin to the beam. It is also used to support the stern when it is desired to ride out at the circle prior to docking or taking off in flight.

The airship carries a main mooring cable on a reel in the bow. In addition, it also carries two coiled trail ropes which can be dropped by pulling a trip in the control car. The main mooring cable is steel wire, 400 feet long, while the trail ropes are manila of about the same length.

In preparing for a mooring on the ground the mast is centered in one or the other of the mooring circles, depending on the direction of the wind, and is anchored securely by four ground hooks located at each corner of the mast. The main mooring cable on the mast is led from the winch, over a buffer device, up through the cup at the top of the mast. Most moorings are made with the mast in the low position. The end of the cable is provided with a quick-coupling device and it is laid out down wind from the mast. The yaw guy cars are positioned on the circular track at points about 30 degrees right and left of the point at which the ship will approach. These cars are clamped to the track. A wire leader with a spider at one end and a quick-coupling device at the other is led over a sheave on the yaw guy cars. The spiders are manned by about 20 men each whose function is to hold the bow of the airship steady against the gusts as the ship is being hauled down. The quick-coupling devices are brought to the outer side of the circle where it is estimated the ship will approach and their position is marked by a large flag.

The airship, in the meantime, has been circling the field in the vicinity, adjusting its trim and state of equilibrium to a point where it can be controlled with facility at the minimum air speed. Altitude is gradually decreased to about 200 feet and the ship headed up wind for the landing flag marking the position of the yaw guy leaders where she will drop her trail ropes. Men couple the trail ropes to the leaders and the men on the spiders run away toward the mast taking and keeping an equal strain on their lines during the whole operation. The ship then lowers its main wire which is coupled to the main wire from the mast. Upon a signal from the ship the main winch is started and the ship's bow is gradually hauled down until the cone on the bow of the airship is locked in the cup on the top of the mast. Water ballast is then pumped into the ship until the stern comes down within reach of the ground. The lower fin is then clamped to the fin carriage which is resting on the top of the riding out car. The ship is now secure and free to ride around the circle with the shifting of the wind.

Should it be decided to dock the airship at this time, the stern beam is brought up to the circular track and jacked down to it. It then travels around and engages the riding out car. In the meantime bridles are secured to points on the three after main frames of the airship. When all is in readiness, the fin carriage, supporting the stern of the airship, is moved from the riding out car to the top of the beam and centered on the beam. In this operation the stern of the ship remains stationary while the beam moves around under it. The bridles on the ends of the beam are then connected to the bridles on the side of the ship and properly tensioned.

The beam then tows the stern of the airship up against the wind until it is lined up with the hangar tracks. When this is accomplished the beam is jacked up off the circular track and placed on the hangar tracks. The spreader gear is connected and when all is ready the mast moves ahead, towing the ship and the beam into the hangar.

The lower fin has been strengthened to withstand the vertical component of the side load on the ship. Additional strengthening is introduced by the placing of X-frames which extend from a point on each side of the lower fin up to Number 3 longitudinal. These X-frames are plainly seen in the stern view of the ship. It has been computed that the maximum wind against which the stern can be hauled up is about 20 miles per hour. Unfortunately, a wind averaging 20 miles per hour generally has gusts which exceed this figure. Very little is known of the structure of a gust, that is, whether it has lateral and vertical dimensions. Hence, for safety's sake 16 miles is usually the top limit at which docking or undocking is attempted. On the other hand, a wind of reasonably high velocity, provided it is steady in direction, is much more desirable for mooring. This permits greater airspeed to be maintained which results in better control of the ship and low ground speed.

The United States ship *Patoka*, an oil tanker, has been fitted with a mast and has been used successfully on numerous occasions by the *Los Angeles*. The *Akron* had moored to this mast once. Mooring to the mast of the *Patoka* is similar in many respects to mooring to a mast on the ground, except that the airship has to drag its main mooring cable across the deck of the *Patoka* where it is secured to the cable on the mast. The yaw guys are then sent down the cable on messenger blocks and made fast to yaw booms. Riding to this mast is similar in all respects to riding to any high mast. This means that the airship must be flown at all times in order to keep the stern out of the water. By use of the elevators and by careful watch on the trim and state of equilibrium it is possible to remain moored to this mast for considerable periods. However, with an airship of the length of the *Macon* the permissible angle of inclination is small. Should this angle be exceeded the stern will drag in the water and possible damage to the lower fin, which

is so necessary to ground handling and docking, will result. For this reason, mooring to the *Patoka* is looked upon with considerable disfavor. Moorings of this type have several other disadvantages. First of all, if the *Patoka* is rolling at all, undue stresses are imparted to the airship, the motion of which is never synchronized with that of the mast. Secondly, the *Patoka* must be underway in a protected roadstead during the process of mooring due to the fact that the yaw booms are fixed and can not be trained to accommodate fluctuations in wind direction except by changing course of the *Patoka*. Thirdly, lack of mobility of a ship of the *Patoka* type makes it necessary to send the ship ahead long before a projected flight. Finally, a flight crew must be on watch at all times, who are under more strain than if they were in actual flight.—"The Military Engineer," July-August, 1934.

HERE, THERE AND OTHER PLACES.

Browsing through old records of past depressions I have come across what seems to me to be a classic of hard times in the far-off days of the republic. The following letter was written by a farmer in 1797 during the severe depression following the Revolutionary War to the editor of the American Museum, a magazine printed in Philadelphia:

"I profess myself to be an honest farmer, for I can say that no man could ever charge me with a dishonest action. I see, with great grief, that all the country is afflicted, as well as myself; everyone is complaining and telling his grievances, but I find they do not tell how their troubles came on them. I know it is common for people to throw the blame of their own misdeeds on others, or at least to excuse themselves of the charge. I am in great tribulation; but, to keep up the above character of an honest man, I cannot, in conscience, say that anyone has brought my troubles on but myself. 'Hard times—no money,' says everyone. A short story of myself, will show how it came hard times, and no money with me, at the age of 65, who have lived well these 40 years.

"My parents were poor, and they put me at 12 years of age to a farmer, with whom I lived till I was 21. My master fitted me off with two stout suits of homespun, four pair of stockings, four woolen shirts and two pairs of shoes. At 21 I married me a wife, and a very good young woman she was. We took a farm of 40 acres on rent. By industry, we gained ahead fast. I paid my rent punctually, and laid by money. In 10 years I was able to buy me a farm of 60 acres, on which I became my own tenant. I then, in a manner, grew rich—and soon added another 60 acres, with which I was content. My estate increased beyond all account. I bought several acres of out-land for my children, who amounted to seven, when I was 45 years old. Along this time I married my oldest daughter to a clever lad, to whom I gave 100 acres of my out-land. This daughter had been a working, dutiful girl, and therefore I fitted her out well, and to her mind; for I told her, to take of the best of my wool and flax, and to spin herself gowns, coats, stockings and shifts, nay, I suffered her to buy some cotton, and make into sheets, as I was determined to do well by her.

"At this time my farm gave me and my whole family a good living on the produce of it; and left me, one year with another 150 silver dollars, for I never spent more than $10 a year, which was for salt, nails and the like. Nothing to wear, eat or drink was purchased, as my farm provided all—with this saving, I put money to interest, bought cattle, fatted and sold them, and made great profit.

"In two years after, my second daughter was courted. My wife says, 'Come, you are now rich, you know Molly had nothing but what she spun—

and no other clothing has ever come into our house for any of us. Sarah must be fitted out a little; she ought to fare as well as neighbor N—'s Betty. I must have some money and go to town.' 'Well, wife, it shall be as you think best. I have never been stingy, but it seems to me that what we spin at home would do.' However, wife goes to town, and returns in a few days with a calico gown, a calamanco petticoat, a set of stone tea cups, half a dozen pewter teaspoons, and a tea kettle, things that were never seen in my house before. They cost but little—I did not feel it—and I confess I was pleased to see them. Sarah was as well fitted out as any girl in the parish.

"In three years more, my third daughter had a spark and wedding being concluded upon; wife comes again for the purse, but when she returned, what did I see! A silken gown, silk for a cloak, a looking-glass, china tea-geer, and a hundred other things with the empty purse. But this is not the worst of it, Mr. Printer. Some time before the marriage of this last daughter, and ever since, this charge increased in my family, besides all sorts of household furniture unknown to us before, clothing of every sort is bought, and the wheel goes only for the purpose of exchanging our substantial cloth of flax and wool, for gauze, ribands, silk, tea, sugar, etc. My butter, which used to go to market, and brought money, is now expended at the tea-table. Breakfast, which used to take 10 minutes, when we were satisfied with milk, or pottage made of it, now takes my whole family an hour at tea or coffee. My lambs, which used also to bring cash, are now eaten at home—or, if sent to market, are brought back in things of no use—so that, instead of laying up $150 every year. I find now that my loose money is gone—my best debts called in and expended—and, being straightened, I cannot carry on my farm to so good advantage so that it brings me not near so much; and further, what it costs me to live (though a less family than formerly, and all able to work) is $50 or $60 a year more than all my farm brings me in. Now this has gone on a good many years, and has brought hard times into my family—and, if I can't reform it, ruin must follow—my land must go, I am not alone. Thirty in our parish have gone hand in hand with me—and they all say—hard times. Now, Mr. Printer, I don't know how you live—maybe you are more frugal than we are, as all of us used to be, but I am still master in my own house. I am determined to alter my way of living to what it was 20 years ago, when I laid up $150 a year. I know I can do it, for I have got all my land yet; with good management it will yield me as much as ever. I will increase my sheep, my flax ground and my orcharding; my produce brings (scarce as money is) as much as it used to do. No one thing to eat, drink or wear shall come into my house, which is not raised on my farm, or in the parish, or in the country, except salt, and iron work for repairing my buildings and tools; no tea, sugar, coffee or rum. The tea-kettle shall be sold. I shall then, Mr. Printer, live and die with a good conscience; my taxes, both State and continental, which appear now intolerable, will then be easy; my younger children and my grandchildren will see a good example before them, and I shall feel happy in seeing a reform of abuses which have been growing on me more than 20 years. If you will tell my story, it may work some good, and you shall have my lasting thanks."

It will be observed that as long as this farmer and his family were Rugged Individualists, living self-maintained lives and producing what they needed to maintain life on their own land, they prospered even though profits were small allowing for all possible differences through a comparison in monetary values. But in these strange days we have substituted for the solid home-spun values a multitude of artificial needs and so-called modern necessities. The pioneering spirit of this rugged farmer of Revolutionary days is what is needed to bring us back to solvency and economic security.—"Marine Journal," July 20, 1934.

BOOK REVIEW.

VENETIAN SHIPS AND SHIPBUILDERS OF THE RENAISSANCE, by FREDERIC CHAPIN LANE. THE JOHNS HOPKINS PRESS, BALTIMORE, 1934. PRICE $3.50.

REVIEWED BY LIEUTENANT H. A. SCHADE, (CC), U. S. N.

Primarily a historical study, written by a historian rather than a technical investigator, this volume yet contains a surprising amount of material of interest to those concerned with the design and building of modern ships. The author states that he was led to study Venetian shipping in the fifteenth and sixteenth centuries with the hope of finding clues to changes in the economic life of the city. The objective is doubtless attained; yet the details of the ships themselves, their design and construction, the lives and methods of the men who built them, and the descriptions of the shipyards of the period and of the Arsenal, form a study so absorbing as to overshadow, in the mind of a technical reader, the broader historical and economic aspects. One is continually surprised to discover how many modern shipbuilding ideas and methods had their close counterparts in the yards of the Venetian builders.

The first few chapters are devoted to a discussion of ship types. Ancient Mediterranean ships had for centuries naturally divided themselves into two primary types, the " long " ships, or galleys, propelled chiefly by oars, and principally used as men-of-war, and the " round " ships, the sailing merchant vessels Although the distinction between the two types so far as usage and method of propulsion are concerned sometimes became obscure or disappeared, yet the " long " ships and the " round " ships remained distinct types, the length-beam ratio of the former being about twice that of the latter. An interesting sidelight reveals that the main hull of the galleys was known as " live work," since upon it depended the strength of the hull, while the superstructures were known as " dead work "; thus, although the beam theory was then unknown,

the Venetians apparently did much as the modern naval architect does when he says that the ship's superstructures do not "work," and hence disregards them in his strength calculations.

Following the descriptions of the ships themselves is a chapter on some famous shipwrights of the times, and another on the craft guilds composed of the various mechanics and laborers who worked on ships. Here we learn that the question of "piece-work" *versus* "day-work" was just as live an issue then as now. The chapter on the processes of construction is filled with interesting details, and apparently even Taylor's system of mathematical lines had its crude counterpart in the *meza-luna,* or half-moon, diagram for proportioning the frames.

The latter half of the book is devoted to the Venetian shipyards, and particularly to the great Arsenal, which would today be called a navy yard. The operation and management of the Arsenal are described in amazingly complete detail, even to such matters as discipline and cost-accounting.

The book is well documented and indexed. The sources referenced are so numerous and obscure as to suggest the enormous amount of research involved in collecting and interpreting the information. The volume will be a scholarly addition to the library of anyone interested in ships and shipbuilding.

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NAVIGATIONAL COMPASSES

GYRO VERSUS MAGNETIC.

By C. HUEY, CIVIL MEMBER,* AND C. E. TAYLOR.†

The word *compass* comes from Old French, compas, a measure, derived from a verb of latin type, *compassare*, to measure off with steps (passus, step). Before the advent of the *gyro compass*, a compass was defined as an instrument to indicate the *magnetic* meridian or position of objects with reference to it. Consideration of the gyro compass requires that the definition be extended to